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Unami et al.

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[54] **PIEZOELECTRIC RESONATOR AND ELECTRONIC COMPONENT CONTAINING SAME**

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[*] Notice: This patent issued on a continued prosecution application filed under 37 CFR 1.53(d), and is subject to the twenty year patent term provisions of 35 U.S.C. 154(a)(2).

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[22] Filed: **Apr. 2, 1997**

[30] **Foreign Application Priority Data**

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Jan. 16, 1997 [JP] Japan 9-020102

[51] Int. Cl.⁷ **H01L 41/053; H03H 19/00**

[52] U.S. Cl. **310/328; 310/348**

[58] Field of Search 310/340, 342, 310/357, 311, 328, 366, 359, 344, 348

[56] **References Cited**

U.S. PATENT DOCUMENTS

1,746,788	2/1930	Marrison	310/359
2,157,665	5/1939	Hollmann	310/315
3,185,869	5/1965	Shoor	310/315
3,297,889	1/1967	Breskend	310/315
3,401,275	9/1968	Curran et al.	310/320
3,590,287	6/1971	Berlincourt et al.	310/328
3,598,506	8/1971	O'Neill	310/328
4,087,716	5/1978	Haywang	310/359 X
4,360,754	11/1982	Toyoshima et al.	310/366
4,398,117	8/1983	St. Cyr	310/348
4,503,352	3/1985	Inoue	333/187 X
4,532,451	7/1985	Inoue	310/359 X
4,542,315	9/1985	Yamamoto et al.	310/348
4,545,553	10/1985	Finke et al.	310/324
4,564,782	1/1986	Ogawa	333/191 X

4,570,098	2/1986	Tomita et al.	310/346
4,633,120	12/1986	Sato et al.	310/328
4,642,510	2/1987	Yamashita	310/348
4,656,385	4/1987	Tanaka	310/348
4,752,712	6/1988	Tomita et al.	310/328
4,759,107	7/1988	Ogawa et al.	310/366 X
4,780,639	10/1988	Shirasu	310/328
4,885,498	12/1989	Wakita	310/328
4,928,030	5/1990	Culp	310/328
5,045,744	9/1991	Ando et al.	310/366 X
5,052,777	10/1991	Ninnis et al.	385/19
5,118,982	6/1992	Inoue et al.	310/328 X
5,126,618	6/1992	Takahashi et al.	310/346
5,153,477	10/1992	Jomura et al.	310/366 X
5,184,332	2/1993	Butler	310/337
5,191,688	3/1993	Takizawa et al.	310/323
5,225,731	7/1993	Owen	310/366
5,233,256	8/1993	Hayashi et al.	310/317
5,237,239	8/1993	Inoue et al.	310/328
5,241,236	8/1993	Sasaki et al.	310/358
5,250,870	10/1993	Fenlon et al.	310/345
5,266,862	11/1993	Ohya	310/328
5,270,984	12/1993	Mine	310/328
5,289,074	2/1994	Mori	310/328
5,378,948	1/1995	Richter	310/328
5,381,067	1/1995	Greenstein	310/359 X
5,410,205	4/1995	Gururaja	310/328

(List continued on next page.)

FOREIGN PATENT DOCUMENTS

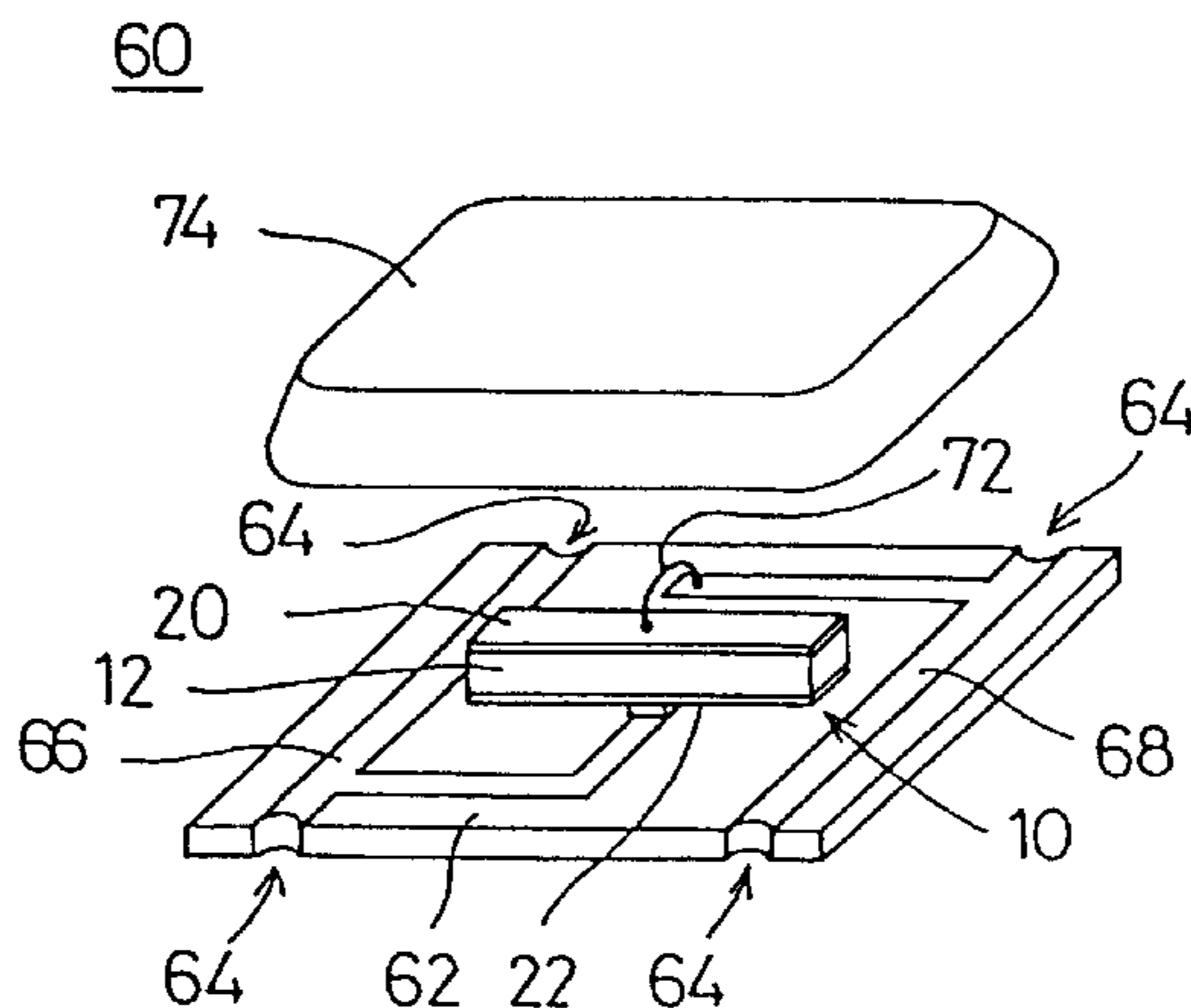
5-160459	6/1993	Japan	310/366
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[57] **ABSTRACT**

A piezoelectric resonator has a base member including laminated piezoelectric layers and internal electrodes. The base member is polarized in different directions at both sides of each internal electrode. The internal electrodes are alternately covered by insulating film on opposing side surfaces of the base member. External electrodes are formed on the opposing side surfaces of the base member and the internal electrodes are connected thereto, respectively.

16 Claims, 23 Drawing Sheets



U.S. PATENT DOCUMENTS

5,438,232	8/1995	Inoue et al.	310/328	5,572,082	11/1996	Sokol	310/366
5,440,195	8/1995	Ohnishi et al.	310/359	5,585,687	12/1996	Wakabayashi et al.	310/366
5,446,485	8/1995	Usui	347/72	5,596,243	1/1997	Tsuru et al.	310/348
5,517,073	5/1996	Ohkuma	310/315	5,596,244	1/1997	Kugou et al.	310/348
5,523,645	6/1996	Inoi	310/364	5,696,472	12/1997	Kaida	333/189
5,525,944	6/1996	Oyama	333/189	5,705,880	1/1998	Shimura et al.	310/366
5,548,179	8/1996	Kaida	310/348 X	5,717,365	2/1998	Kaida et al.	333/187
5,565,824	10/1996	Nagano	333/189	5,825,262	10/1998	Inoue et al.	310/328
				5,834,879	11/1998	Watanabe et al.	310/328

FIG. 1

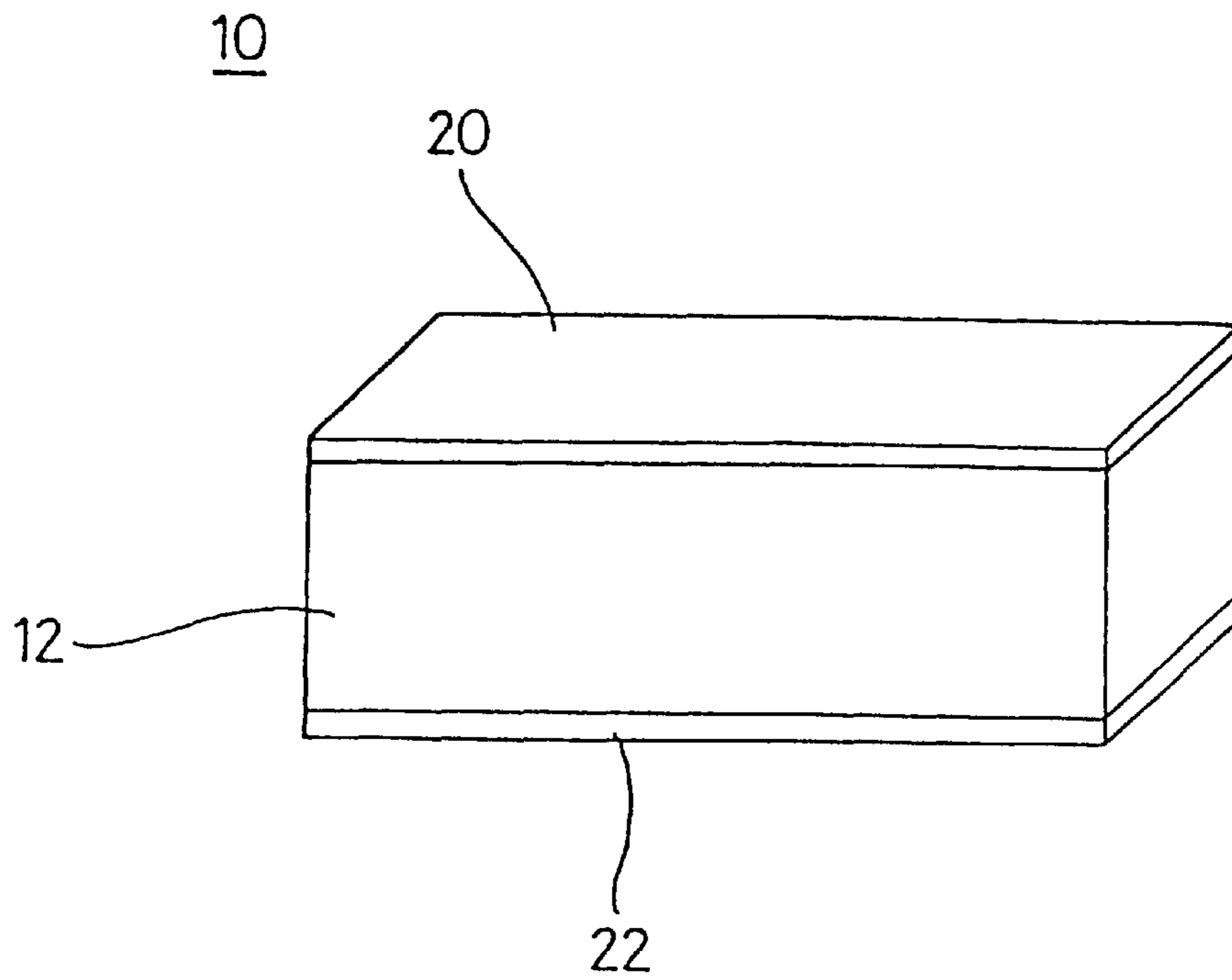


FIG. 2

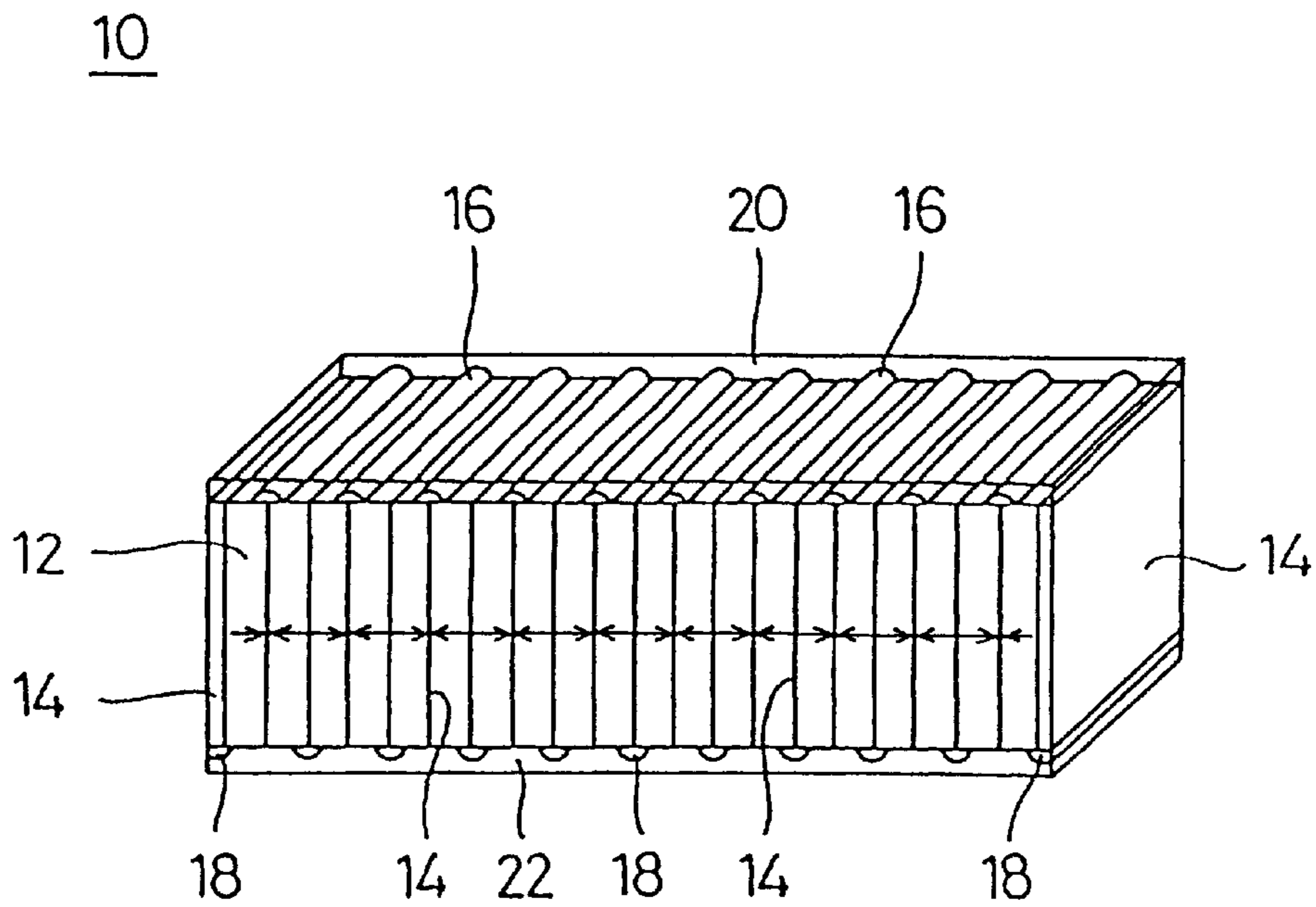


FIG. 3

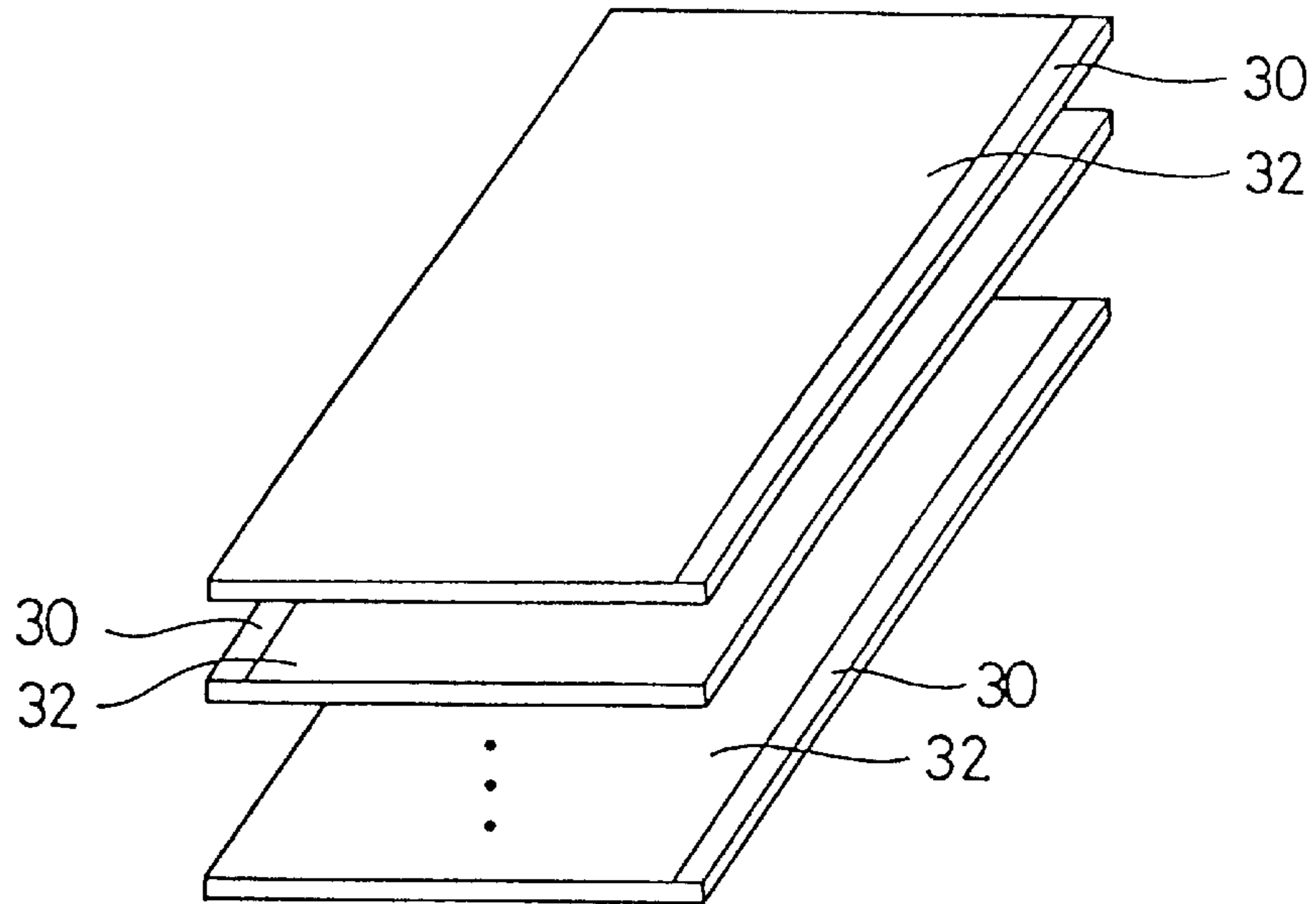


FIG. 4

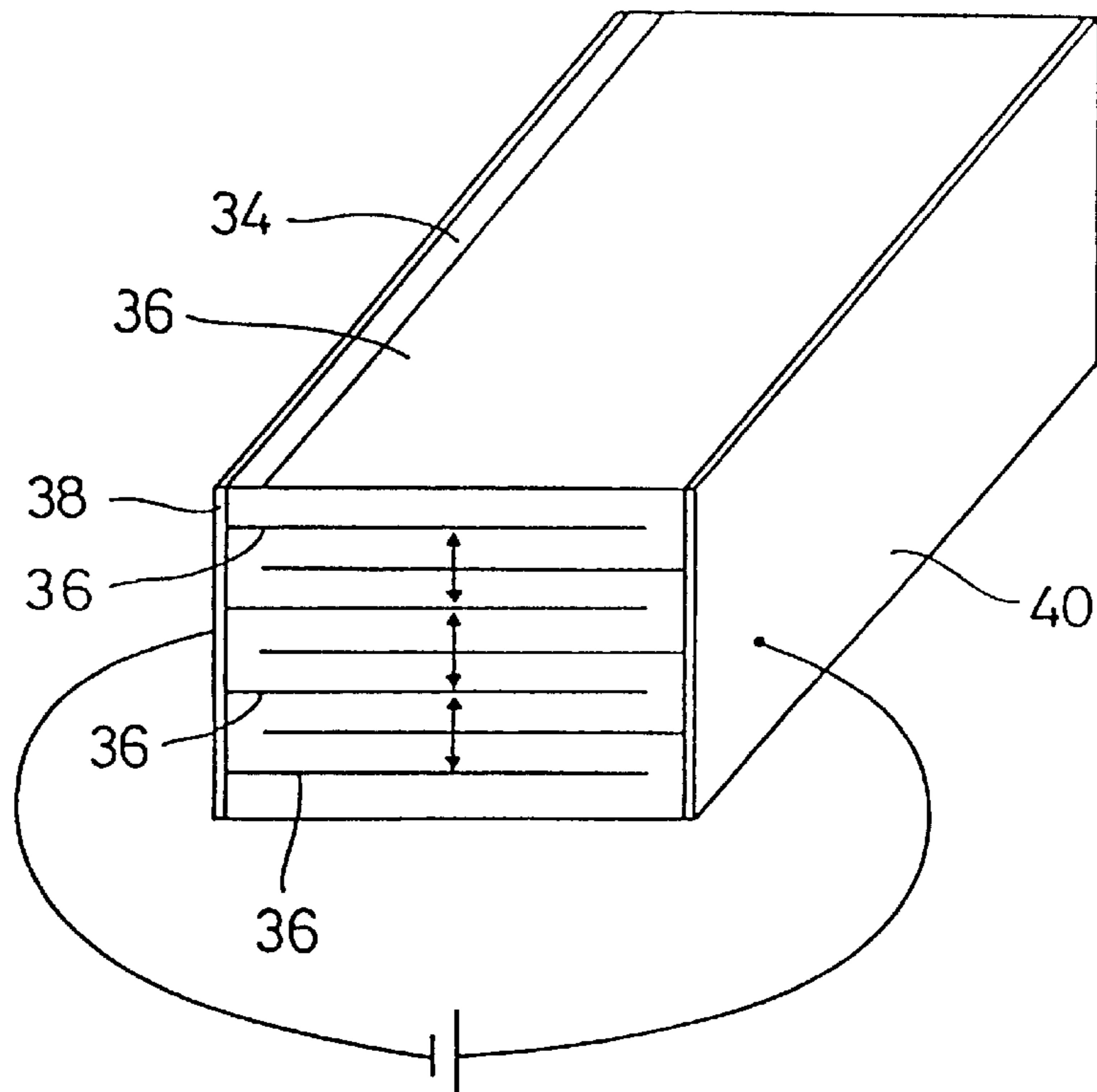


FIG. 5

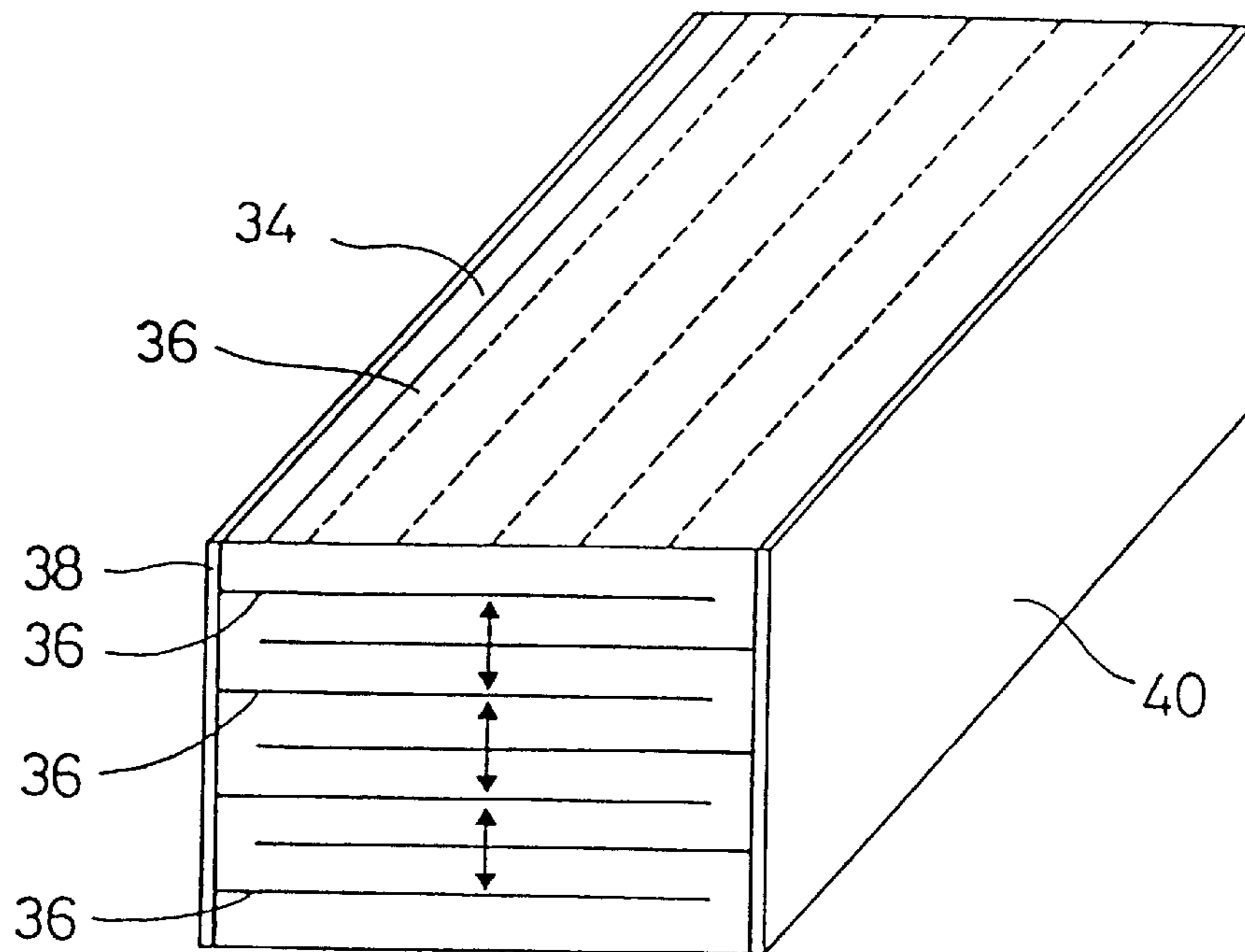


FIG. 6

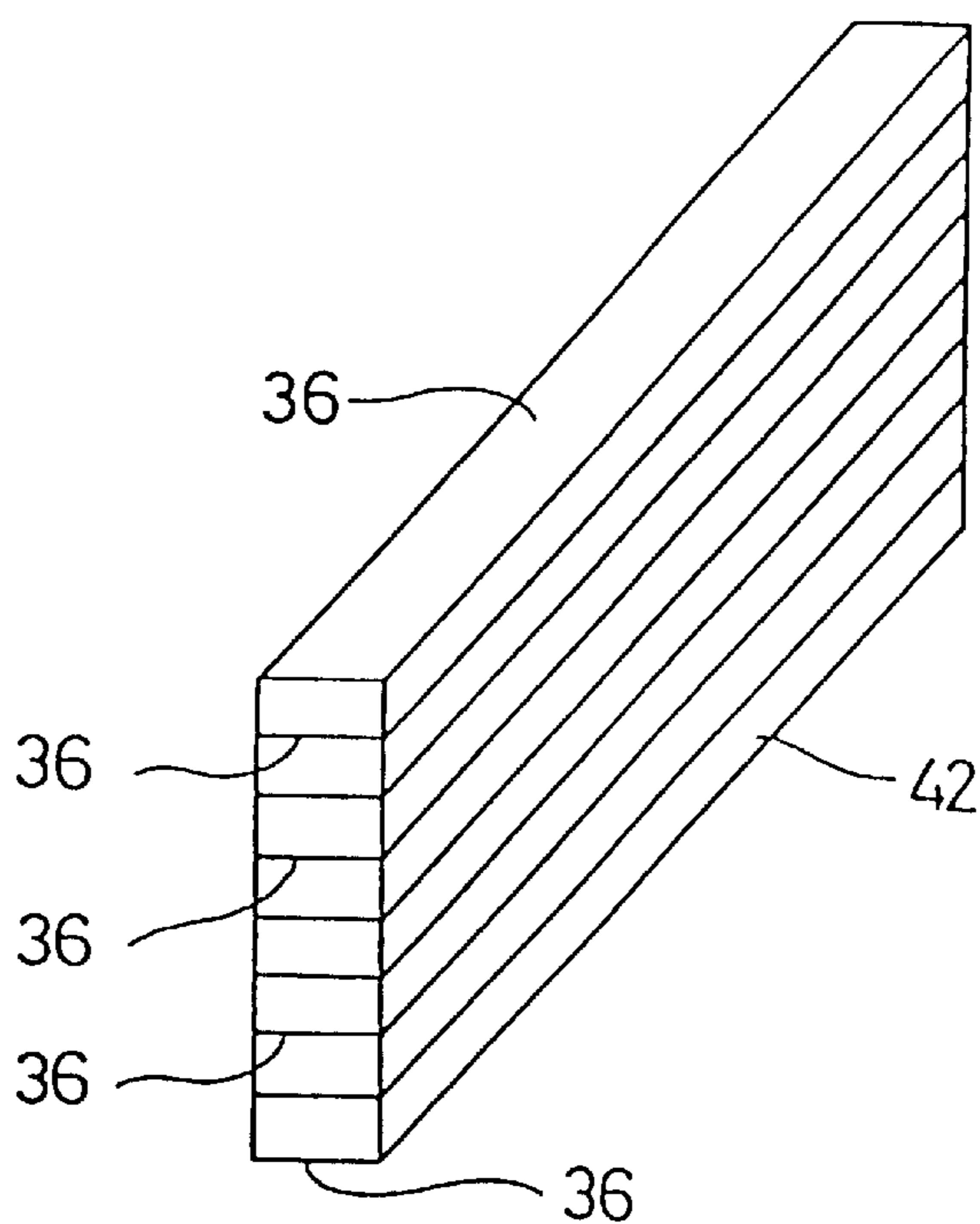


FIG. 7

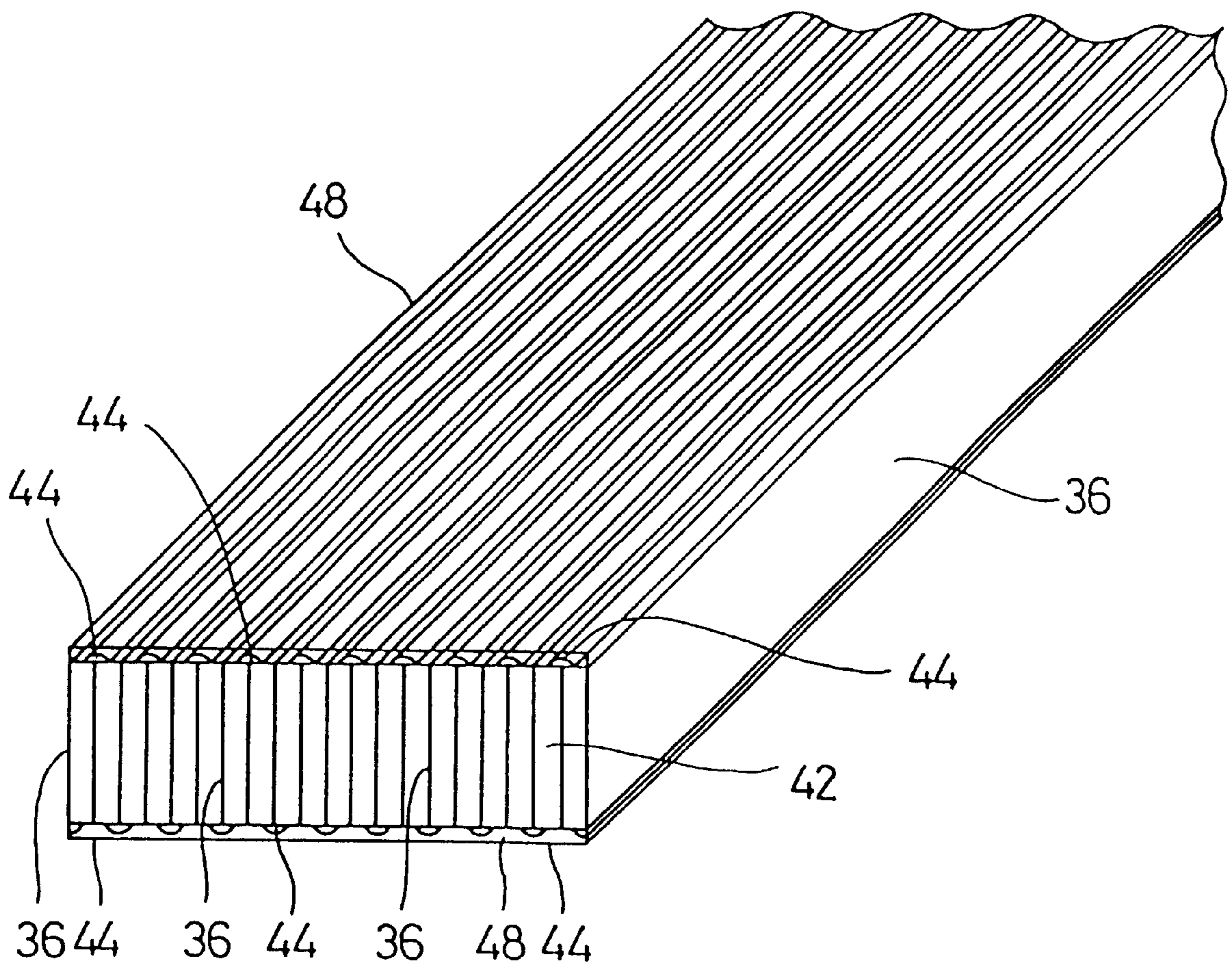


FIG. 8

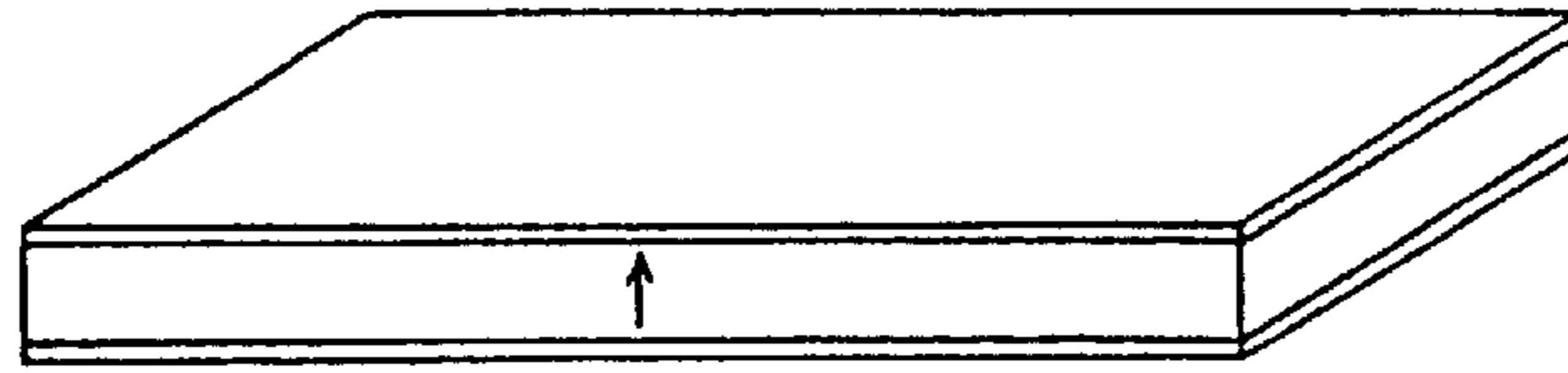


FIG. 9

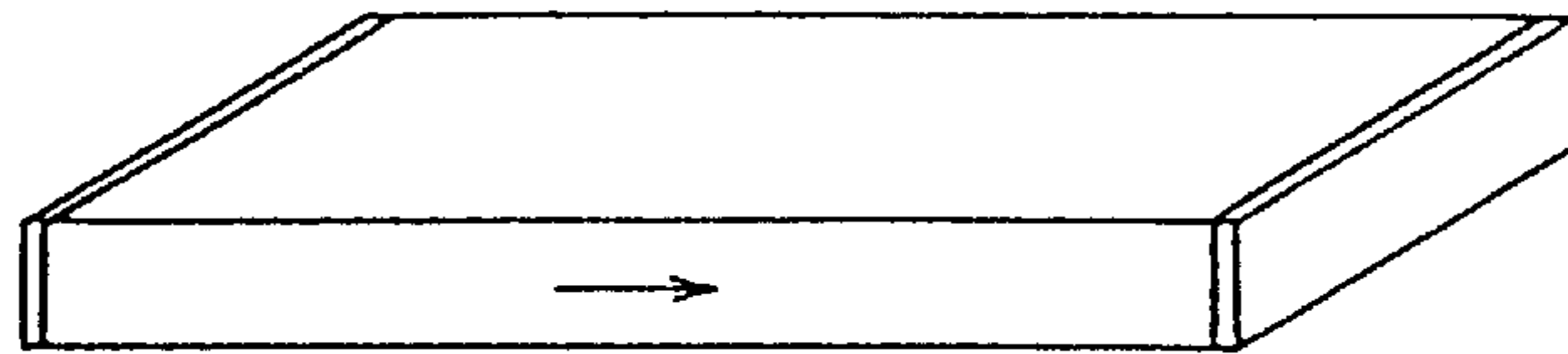


FIG. 10

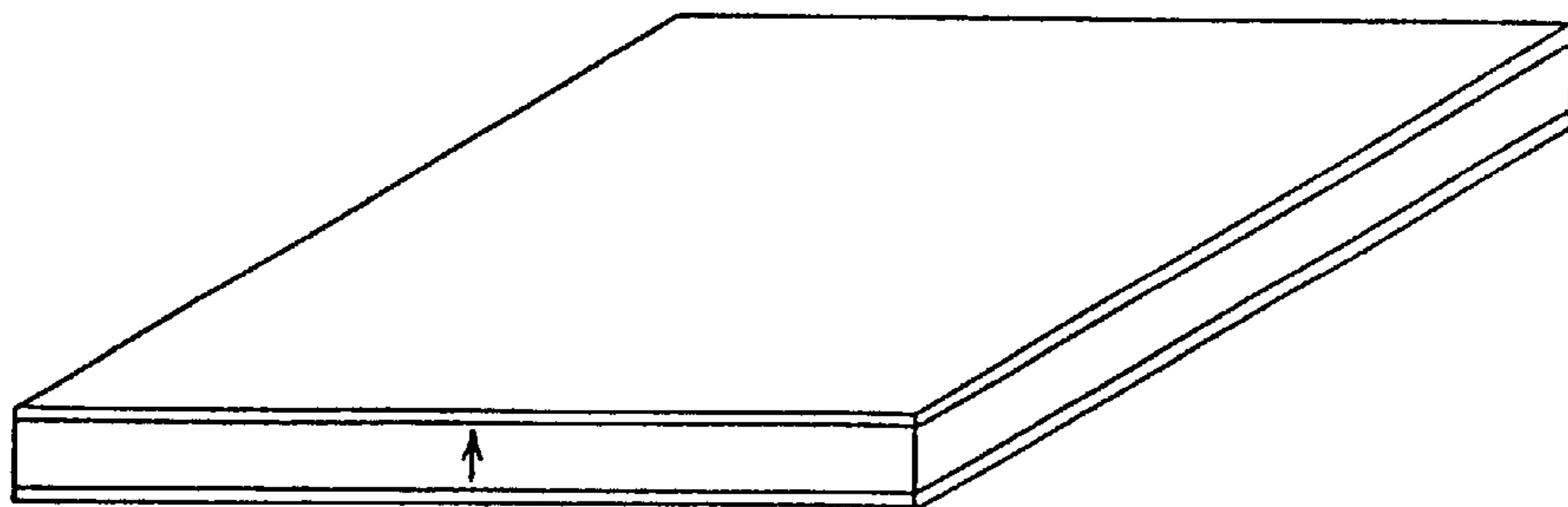


FIG. 11

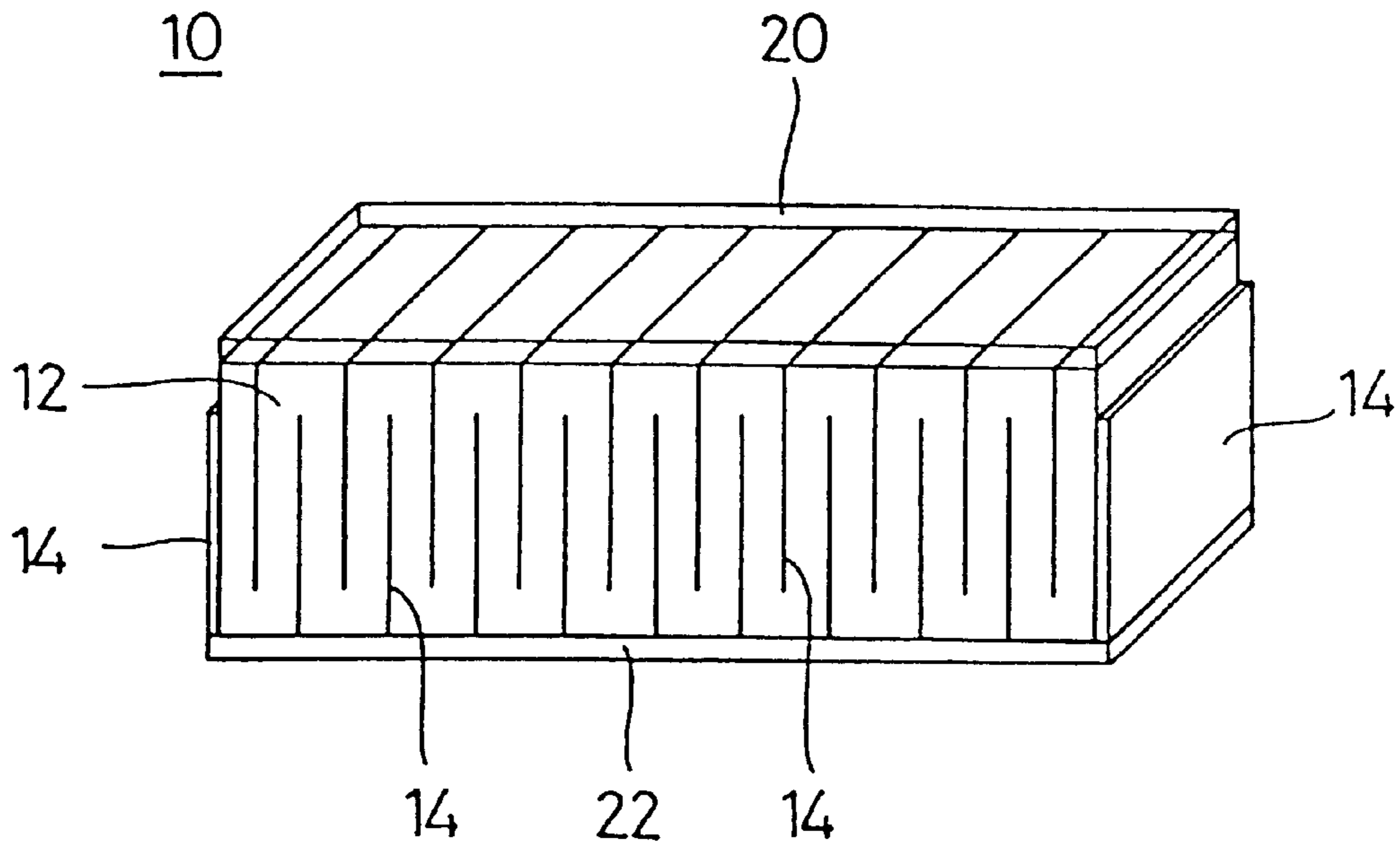


FIG. 12

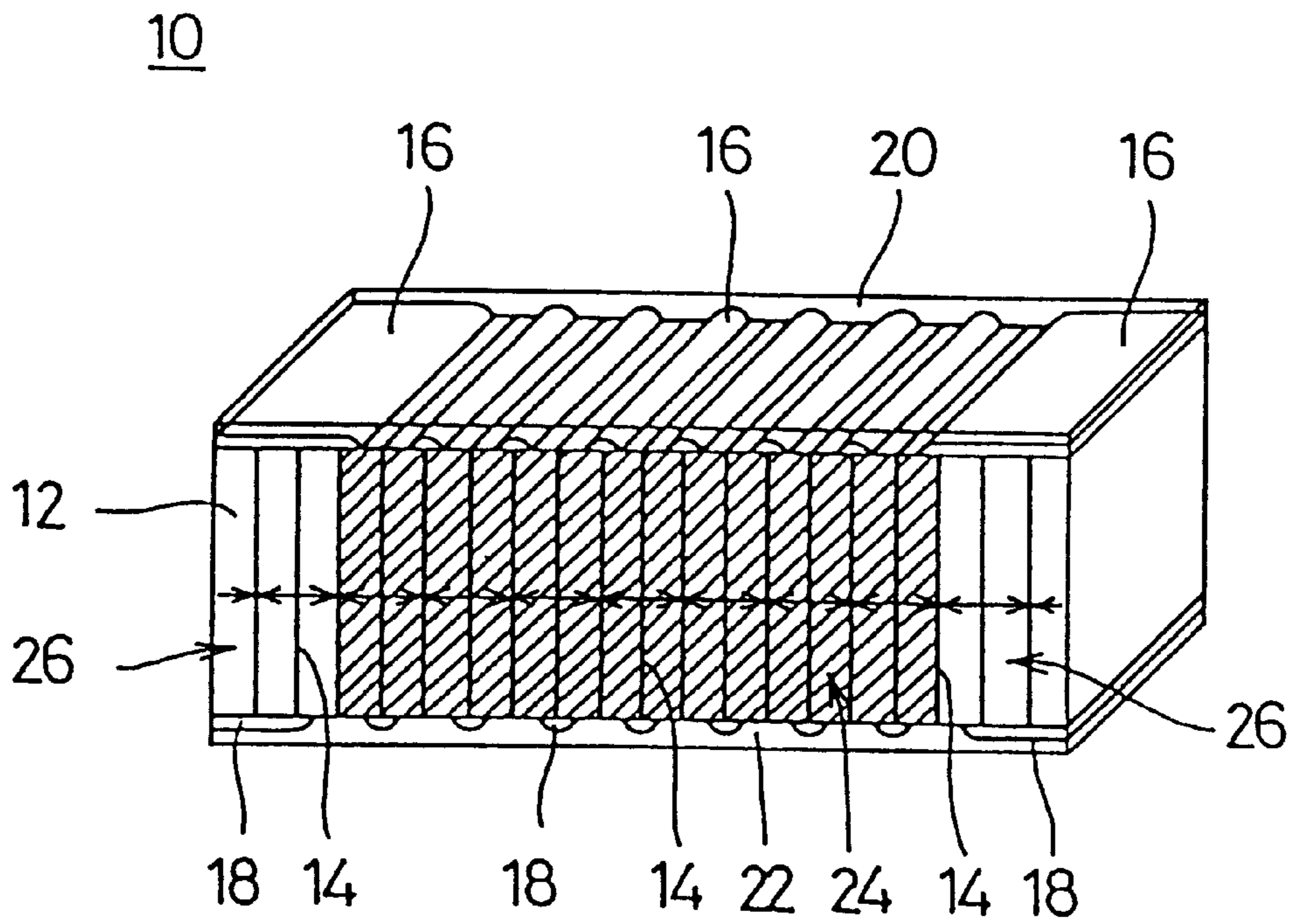


FIG. 13

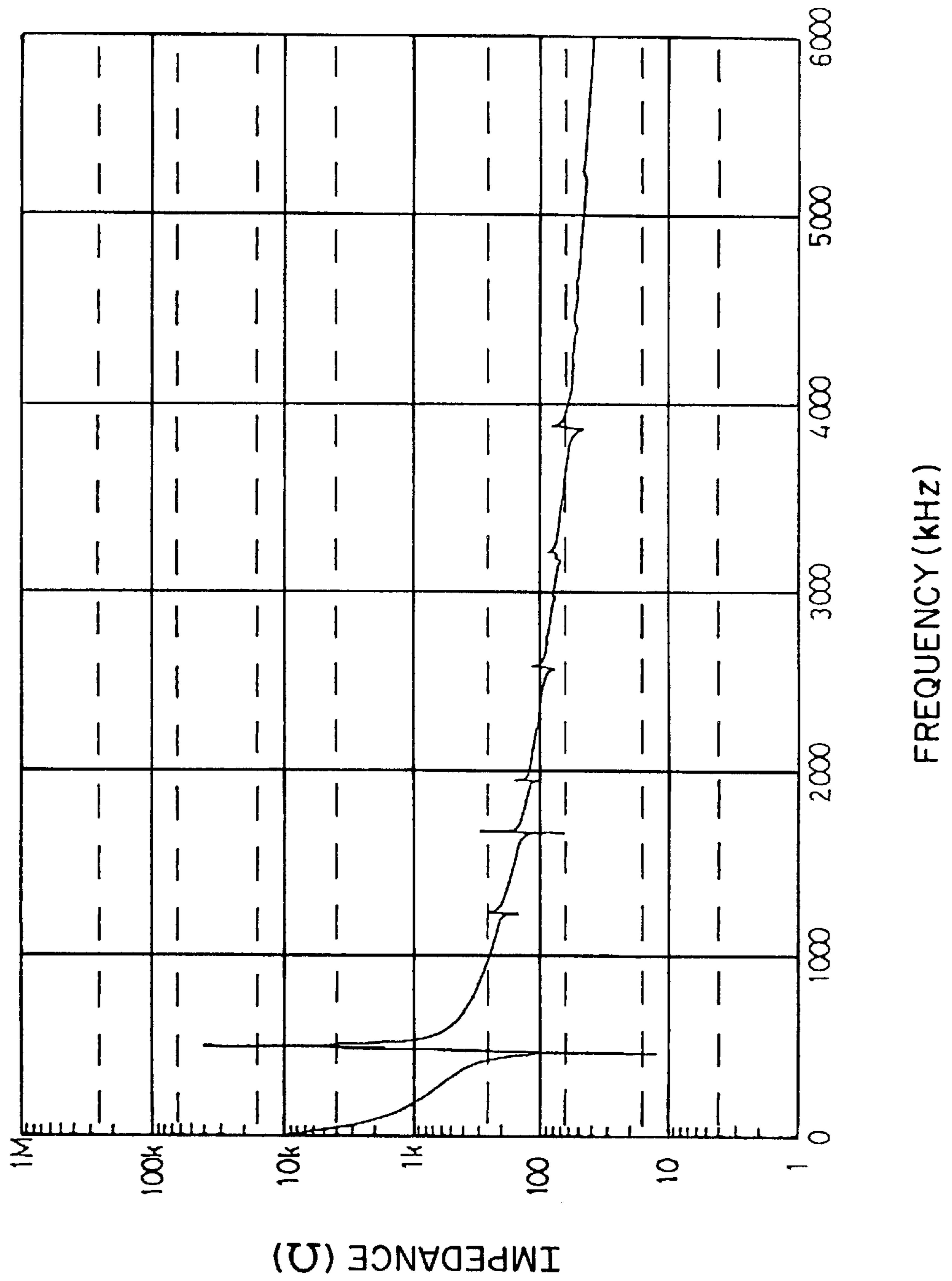


FIG. 14

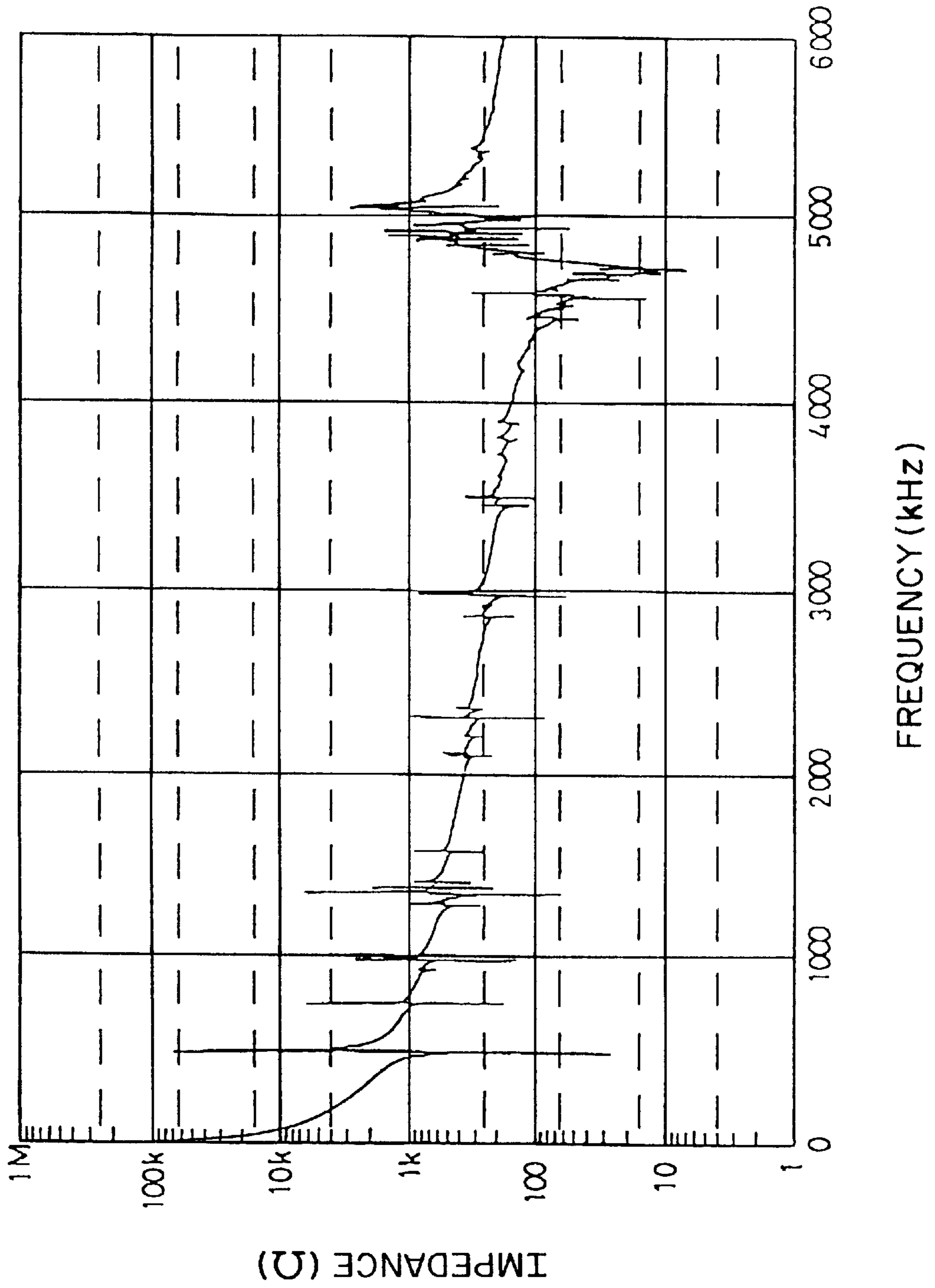


FIG. 15

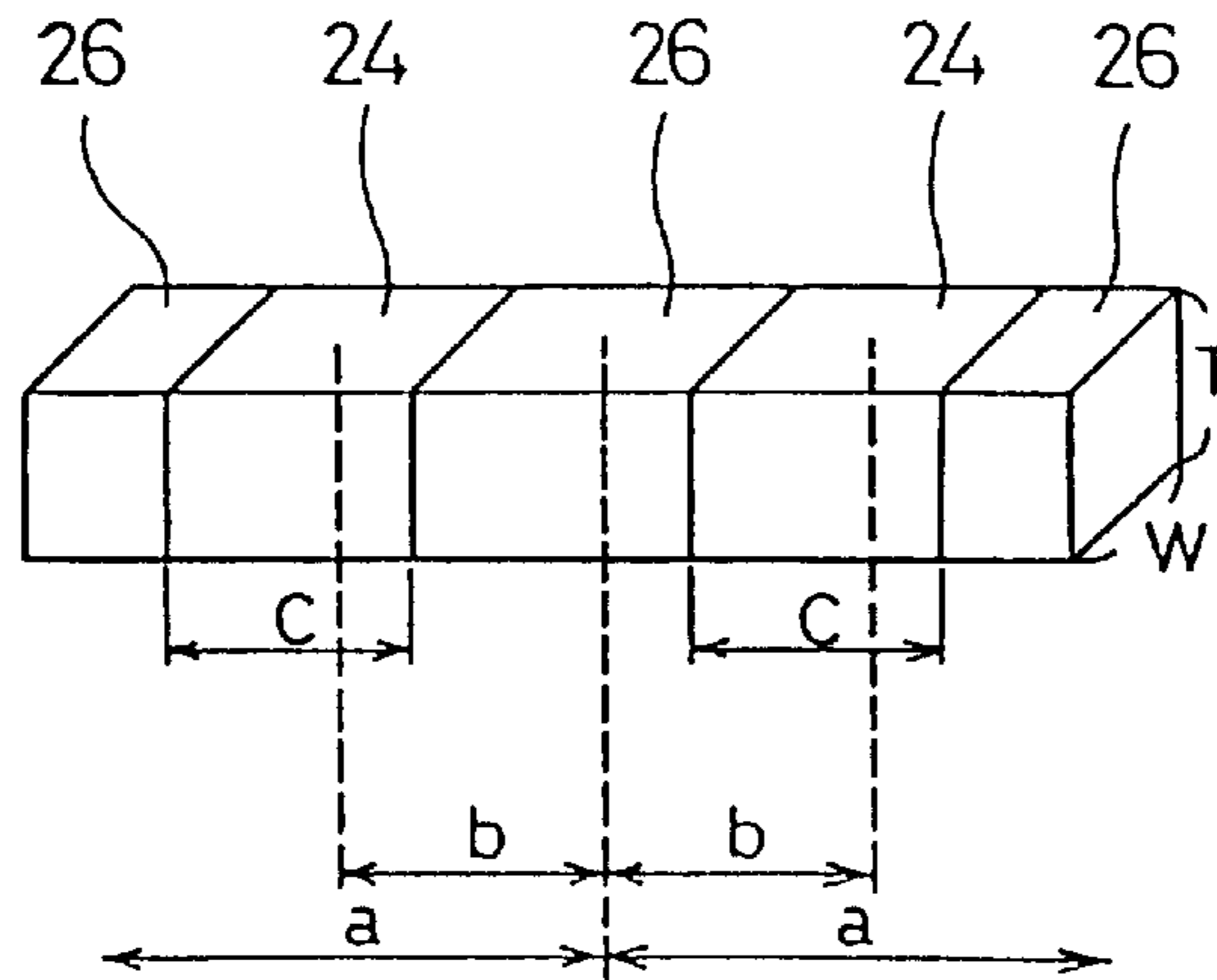


FIG. 16

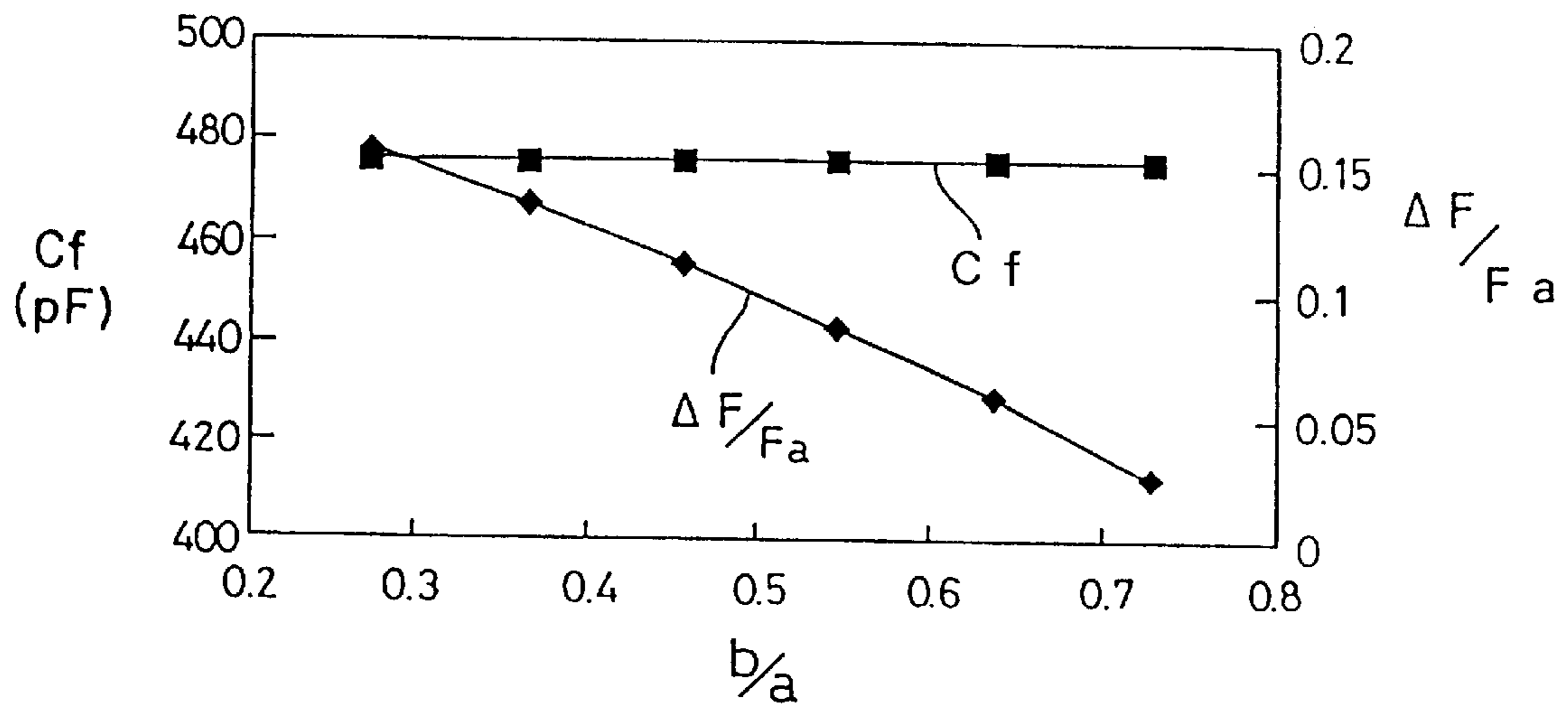


FIG. 17

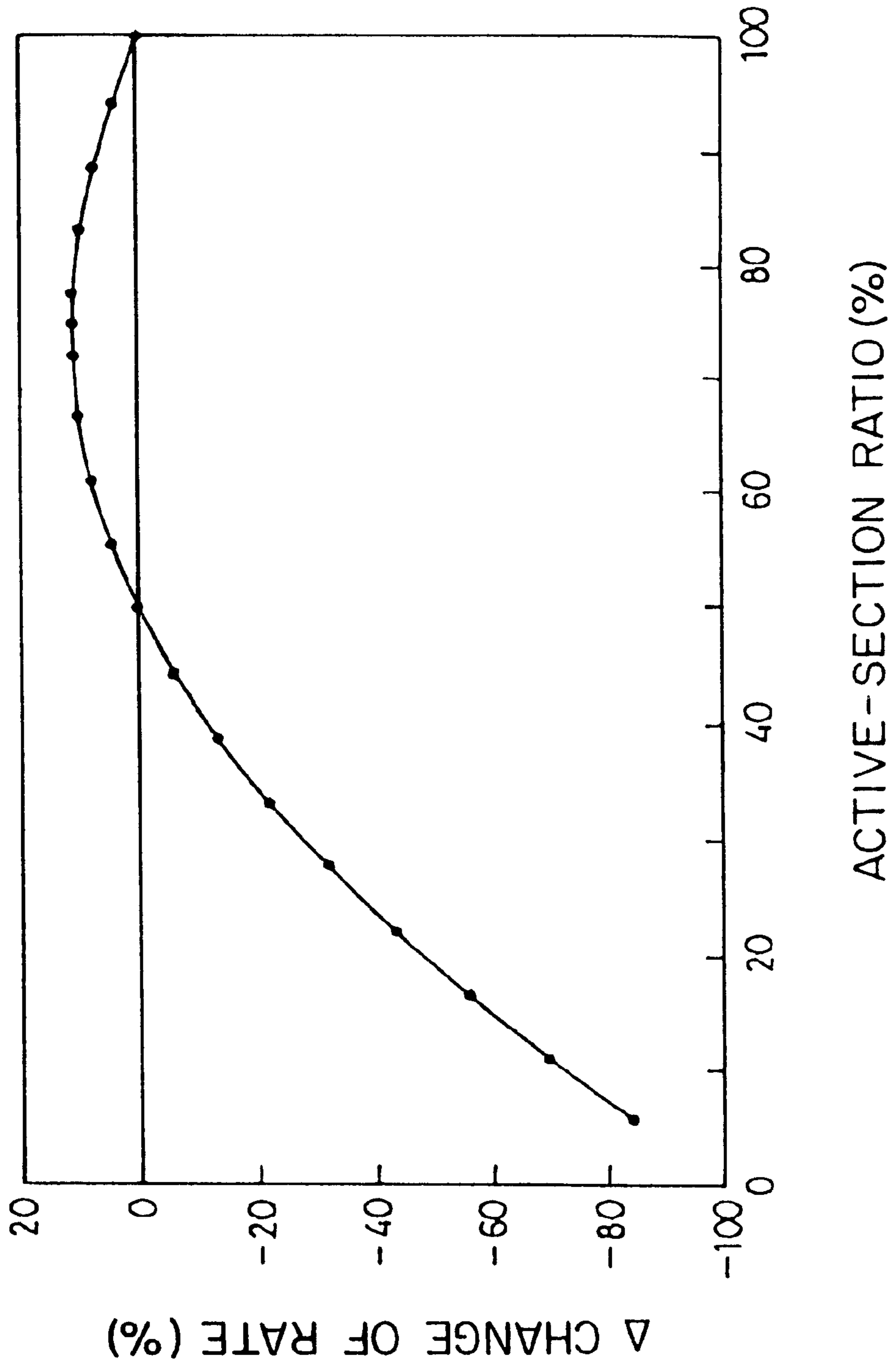


FIG. 18

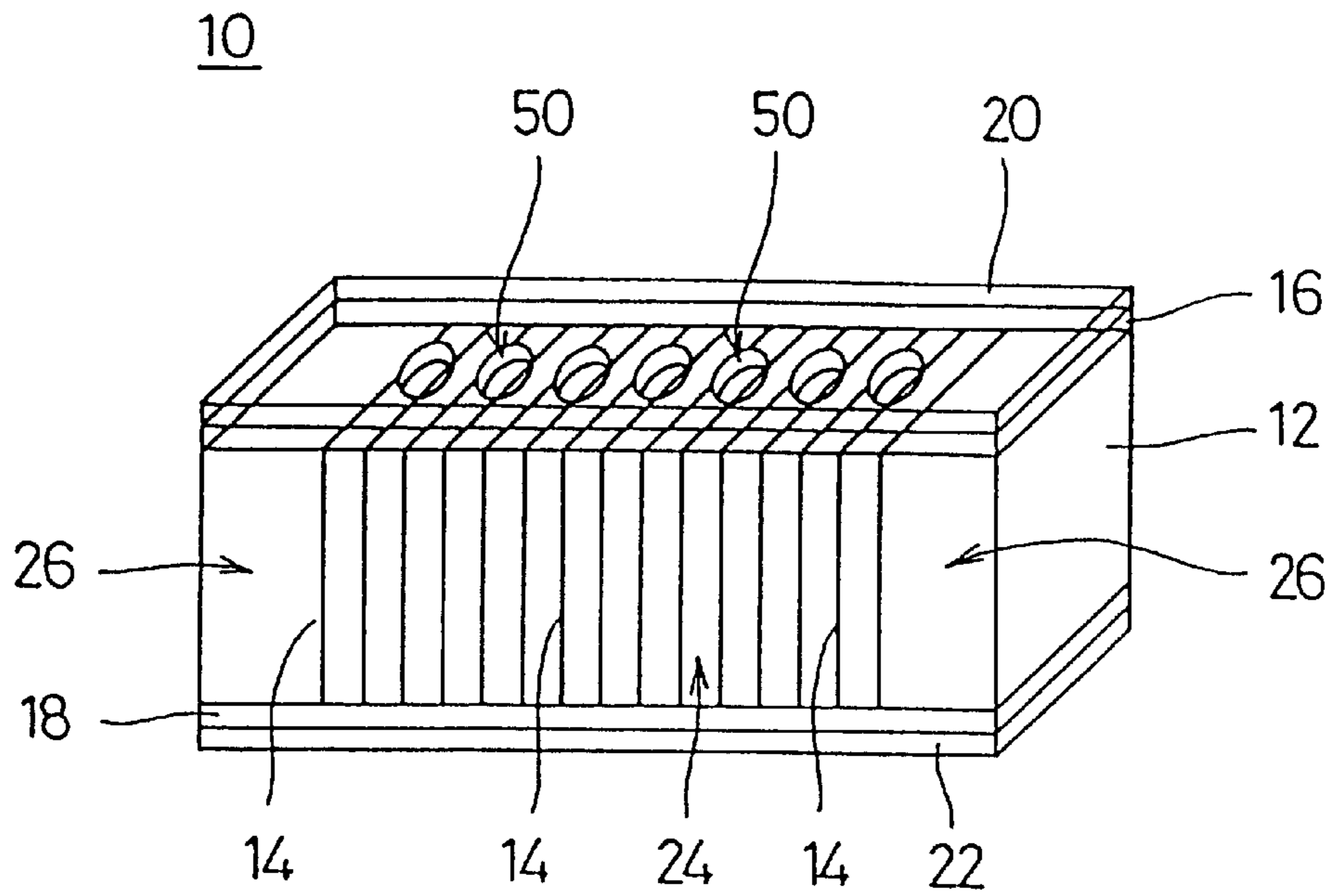


FIG. 19

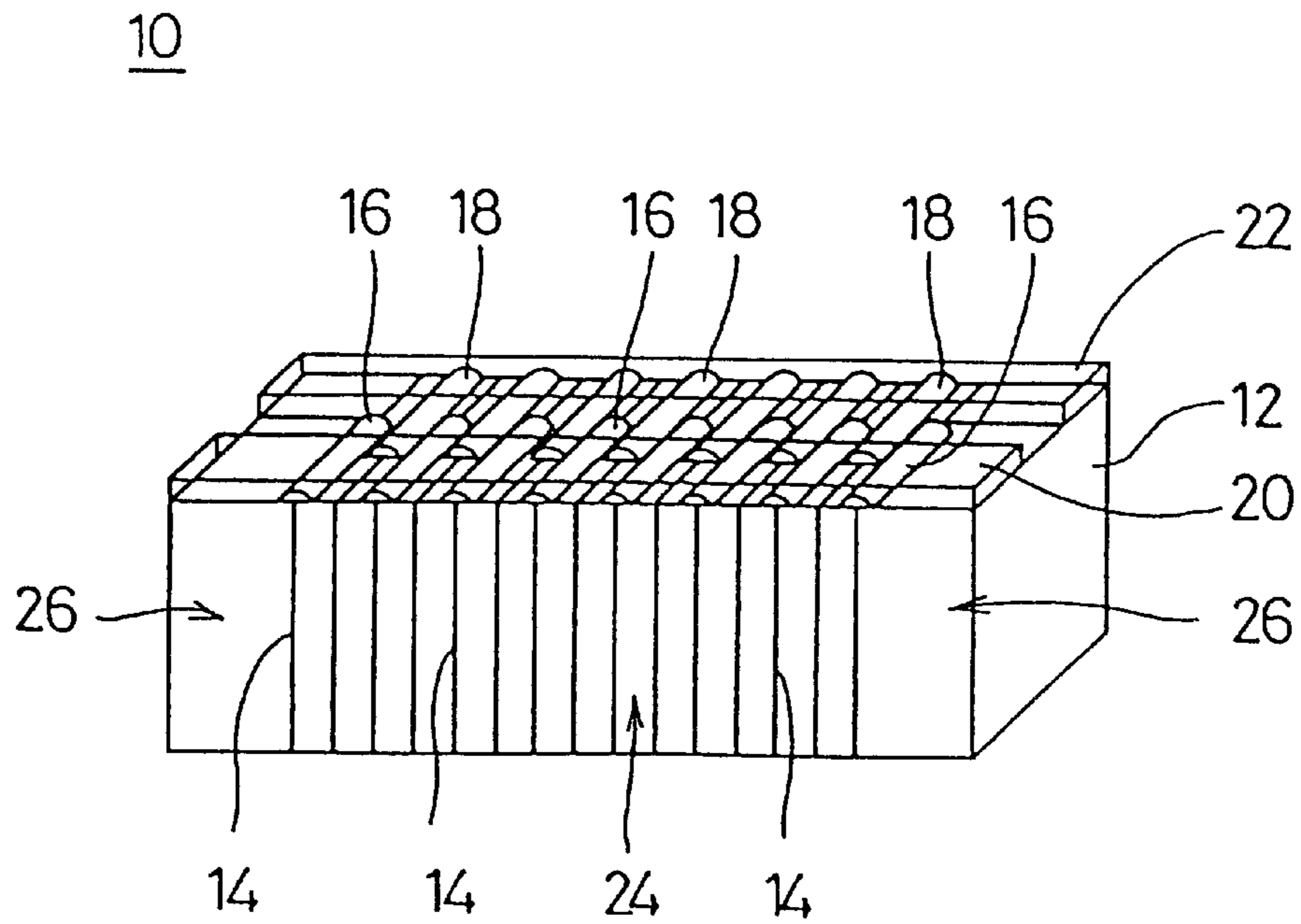


FIG. 20

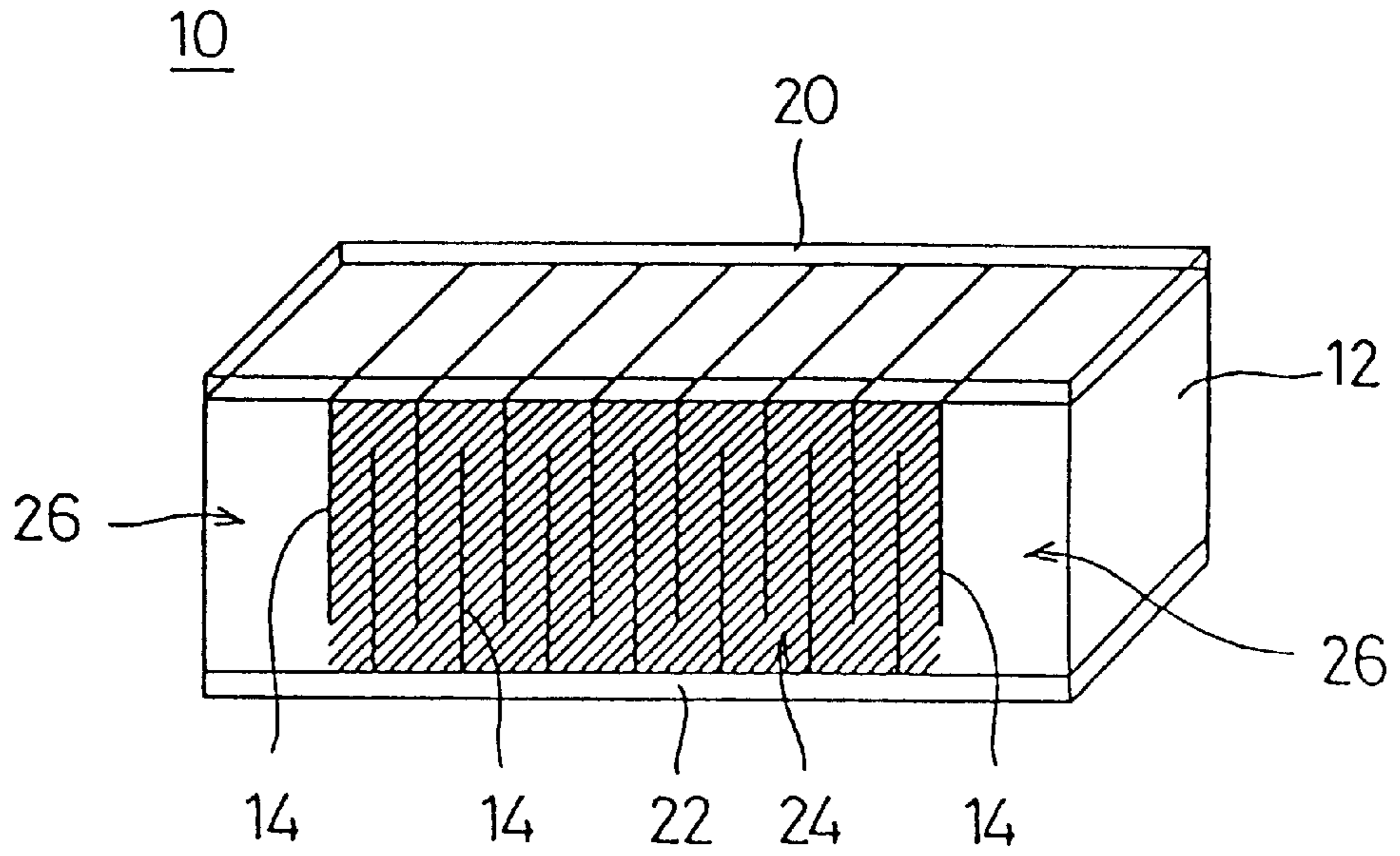


FIG. 21

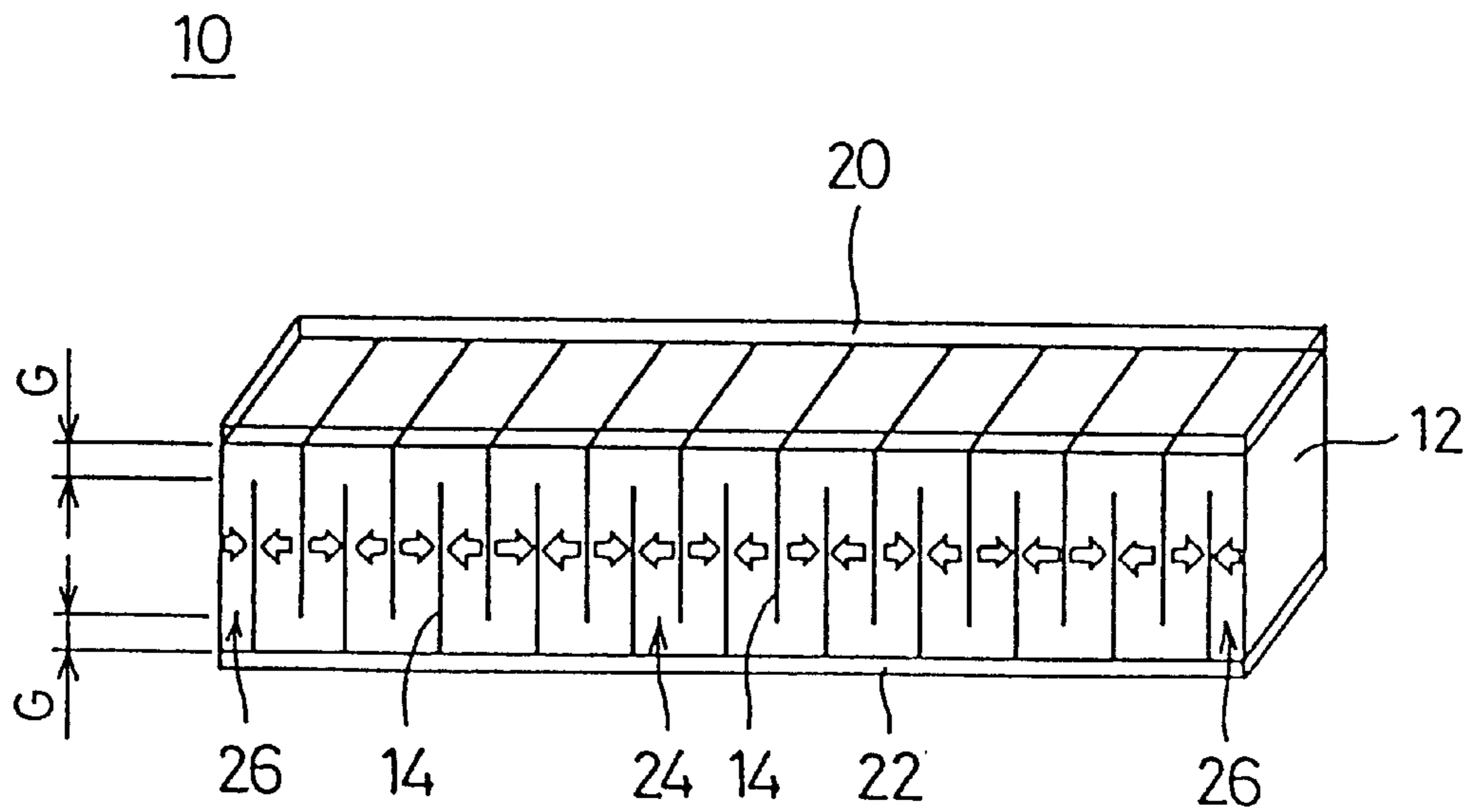


FIG. 22

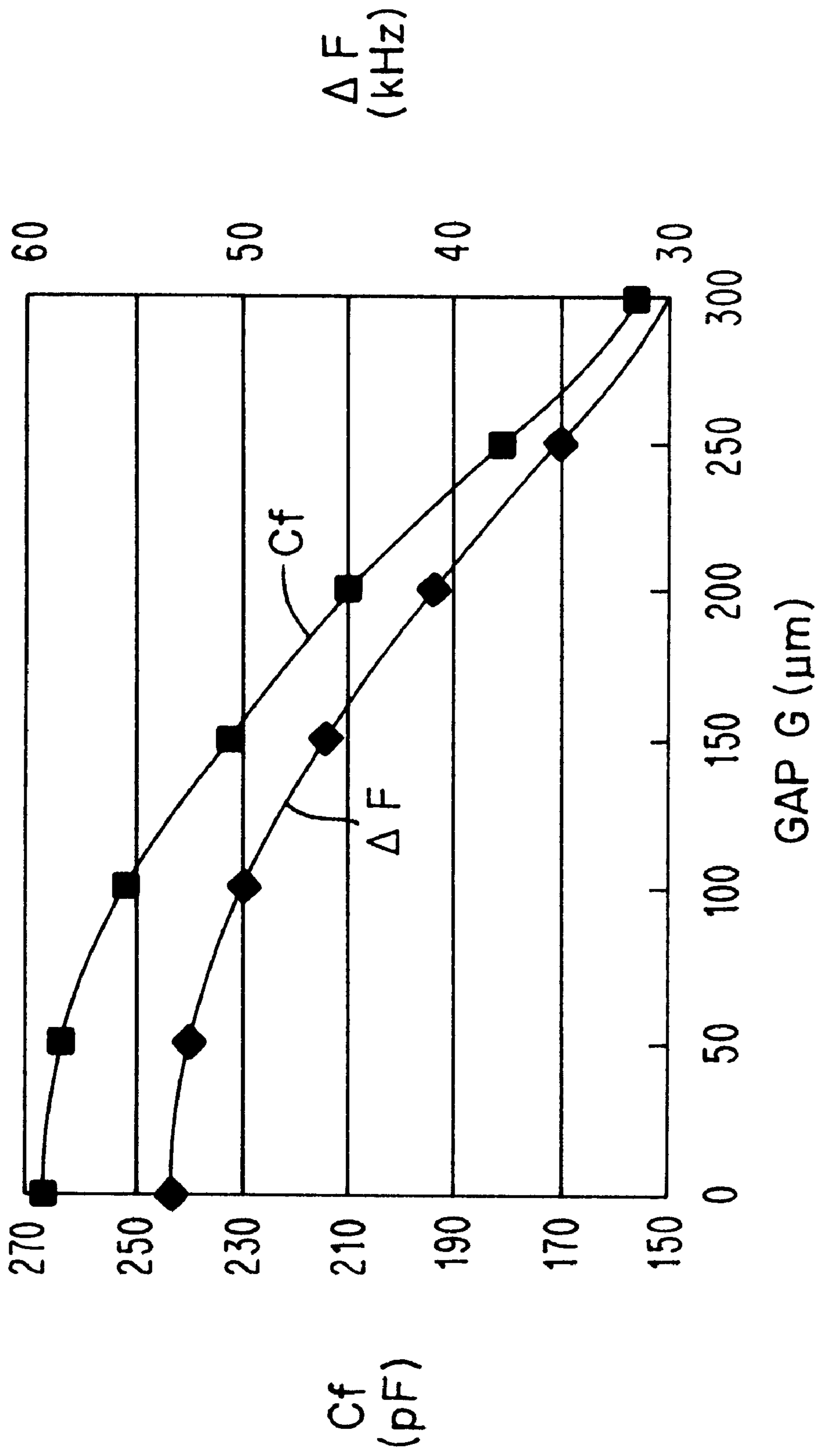


FIG. 23

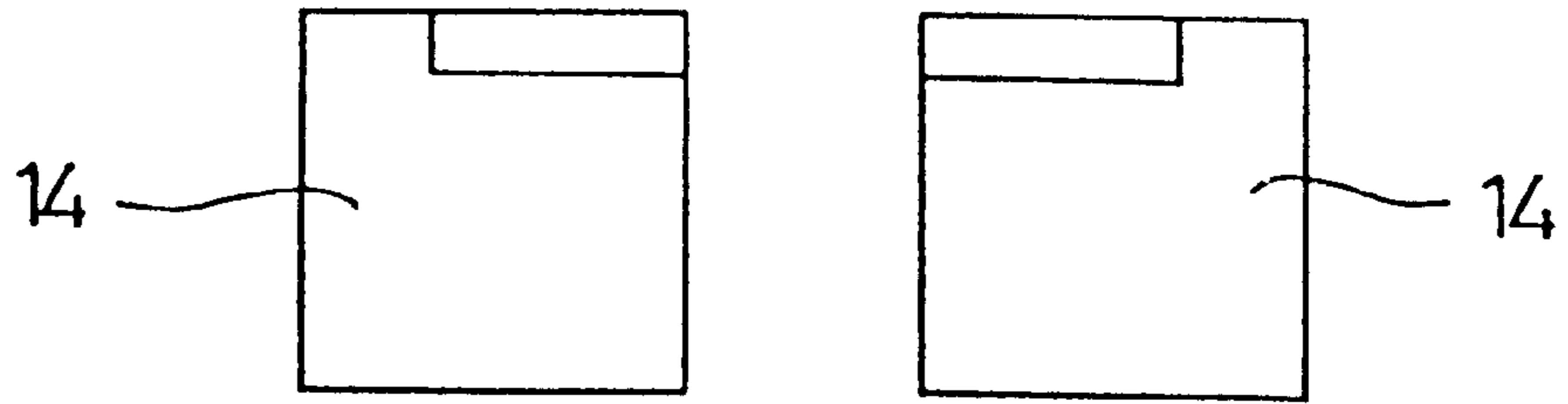


FIG. 24

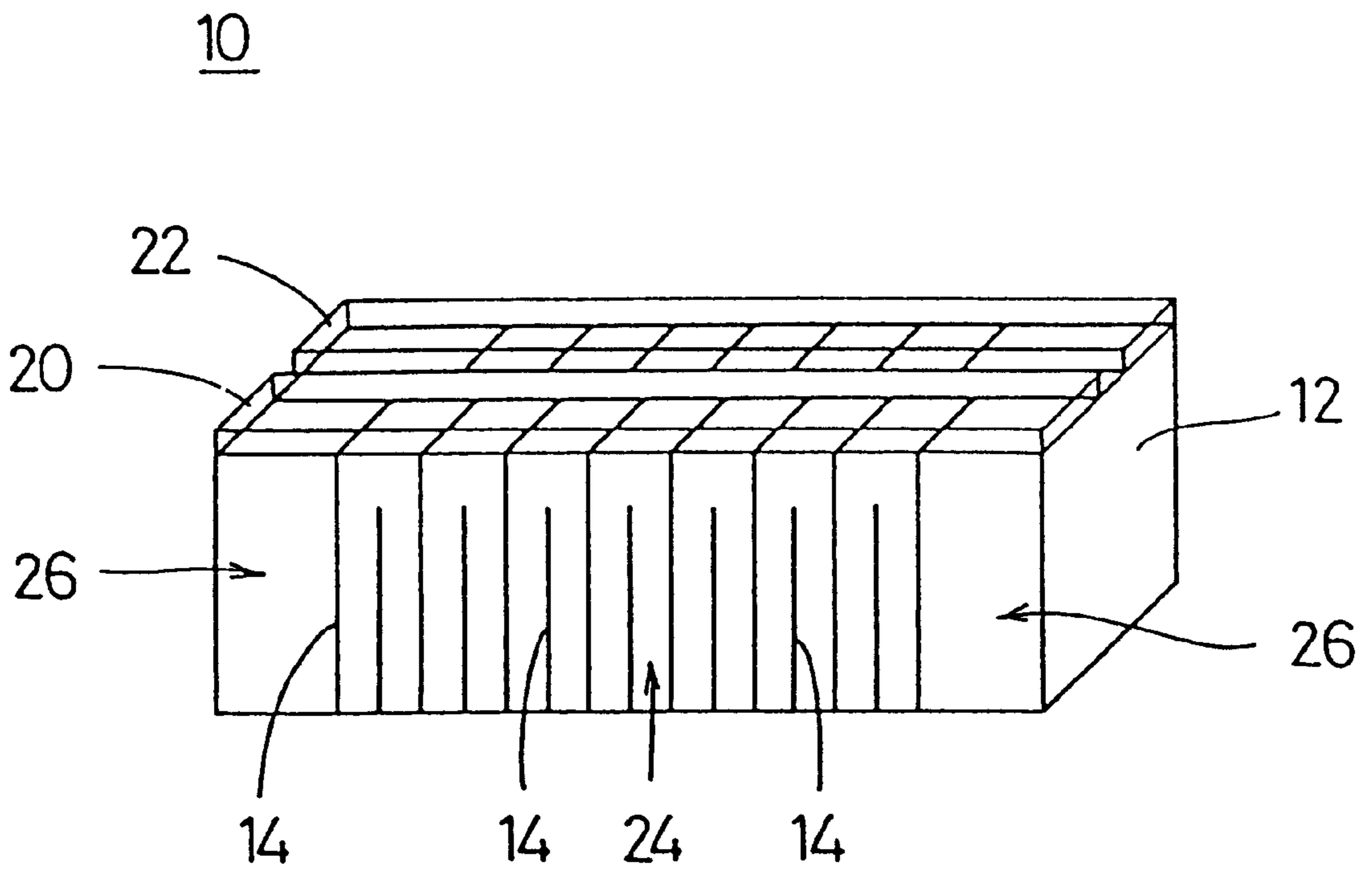


FIG. 25

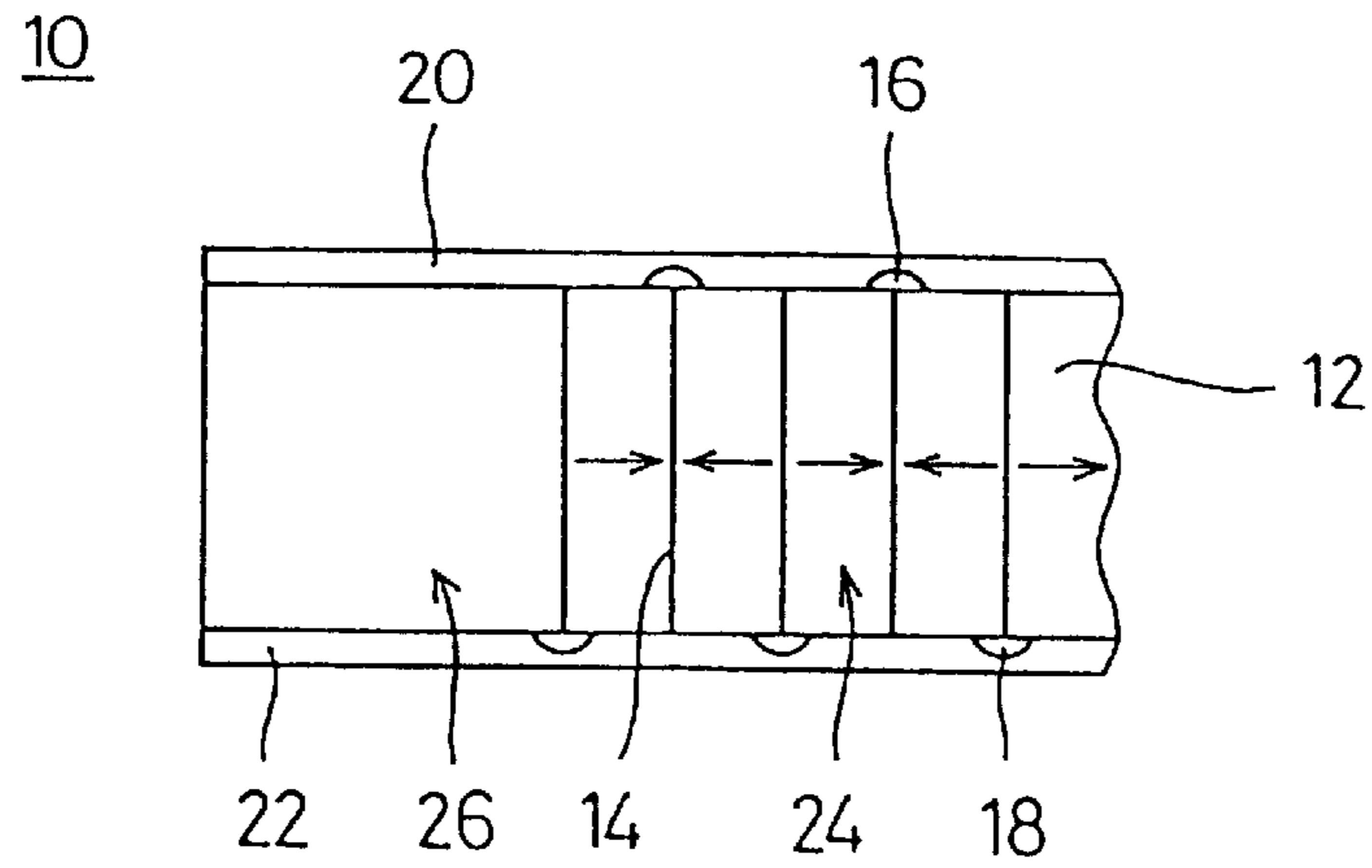


FIG. 26

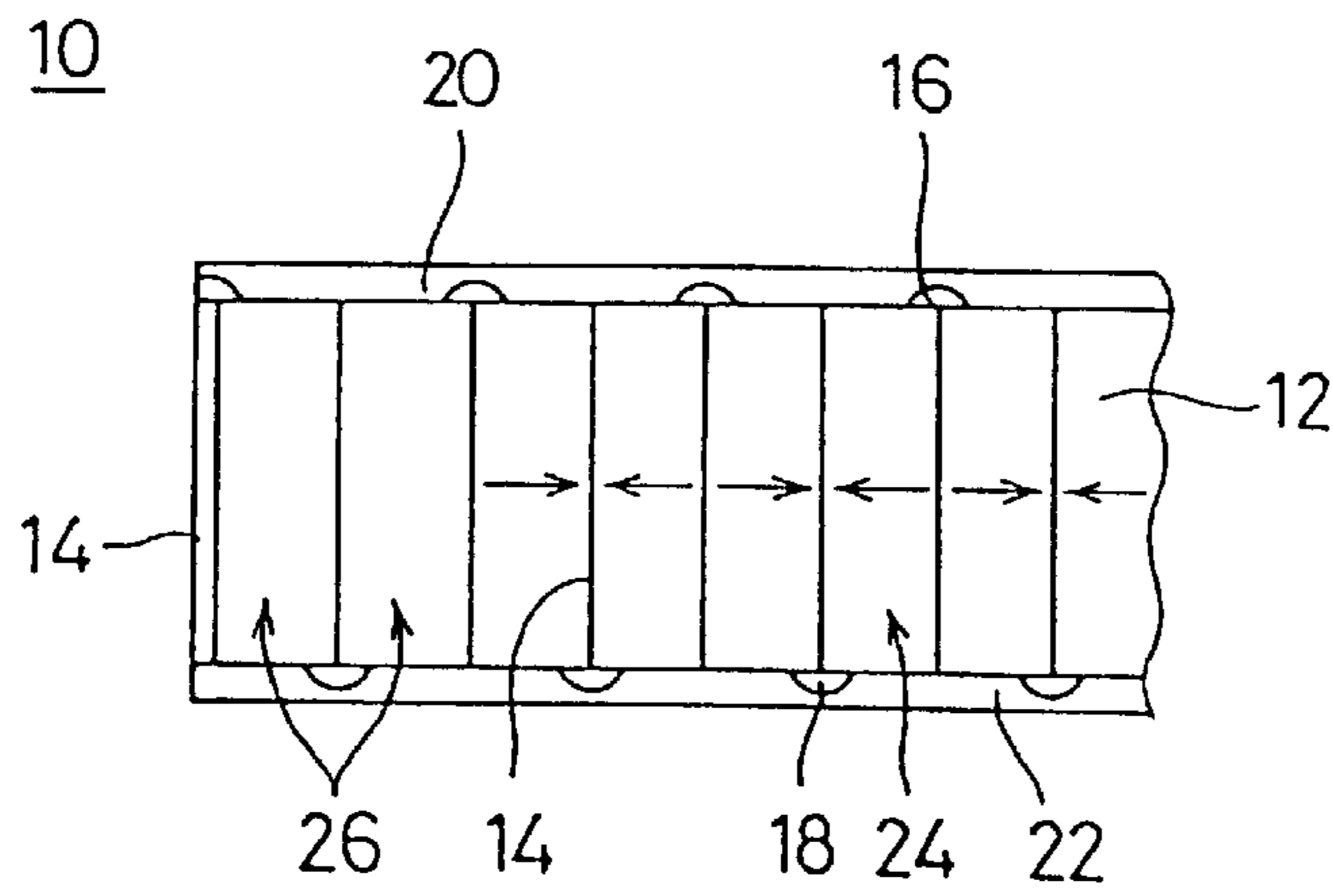


FIG. 27

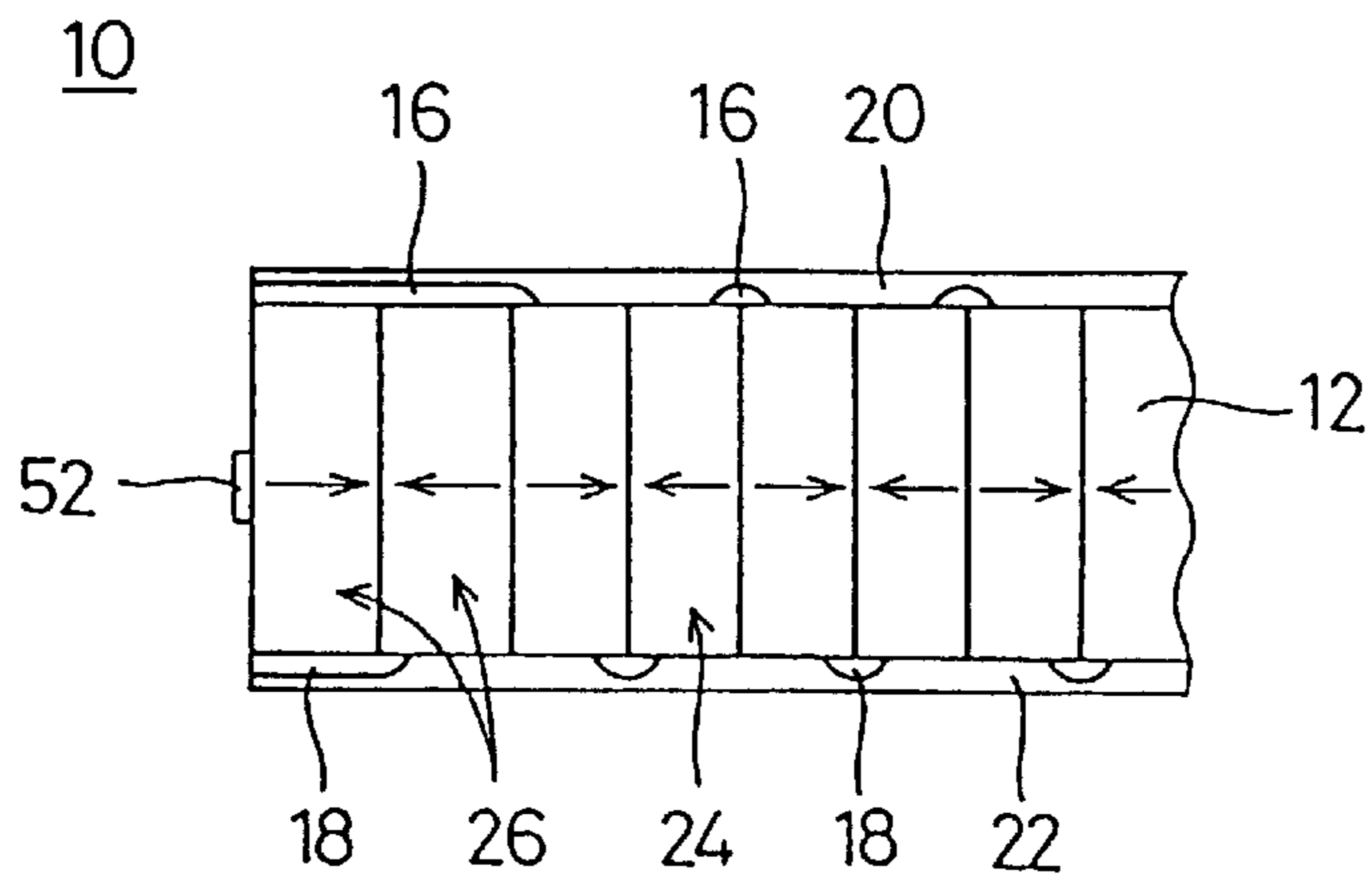


FIG. 28

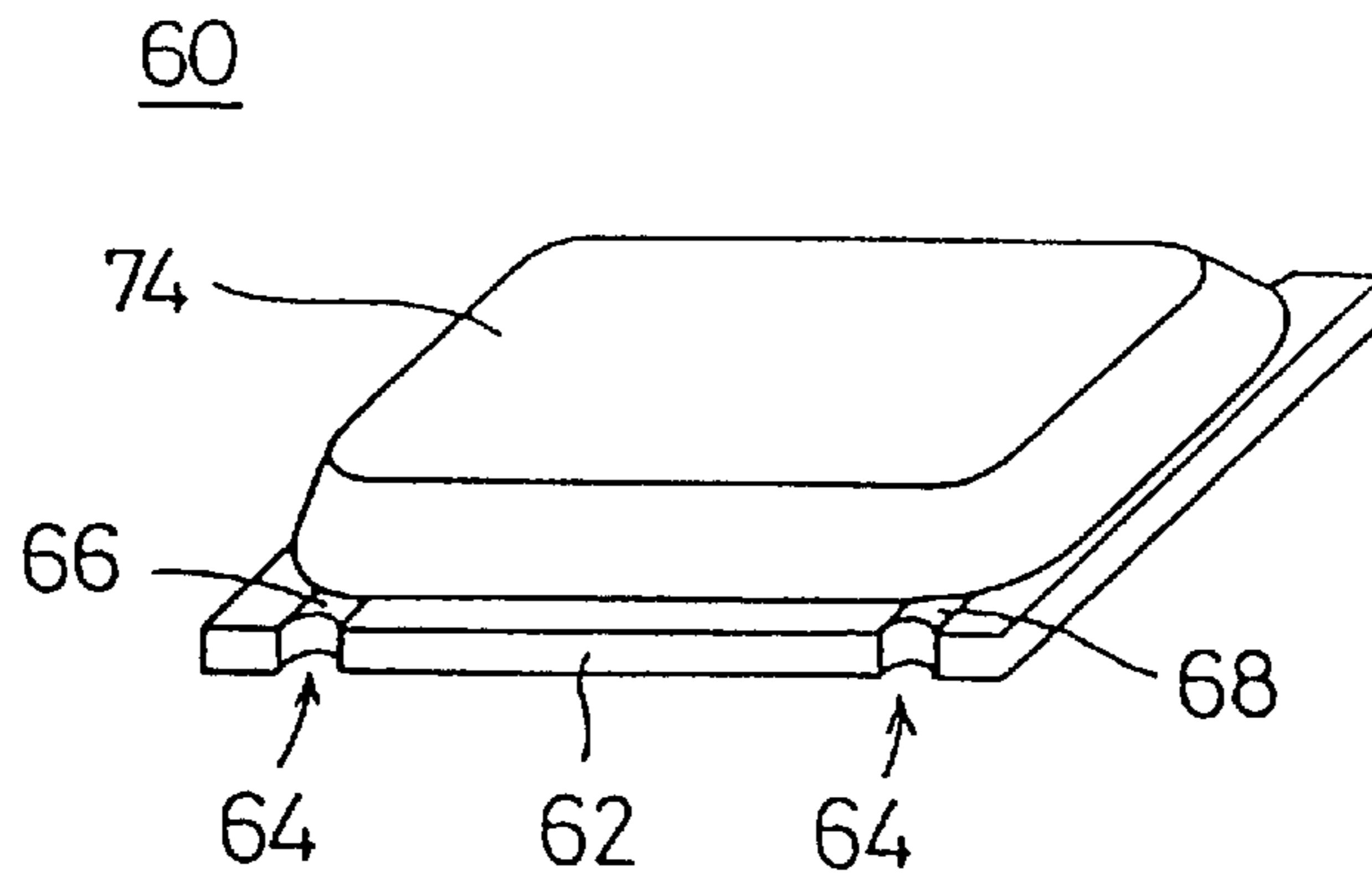


FIG. 29

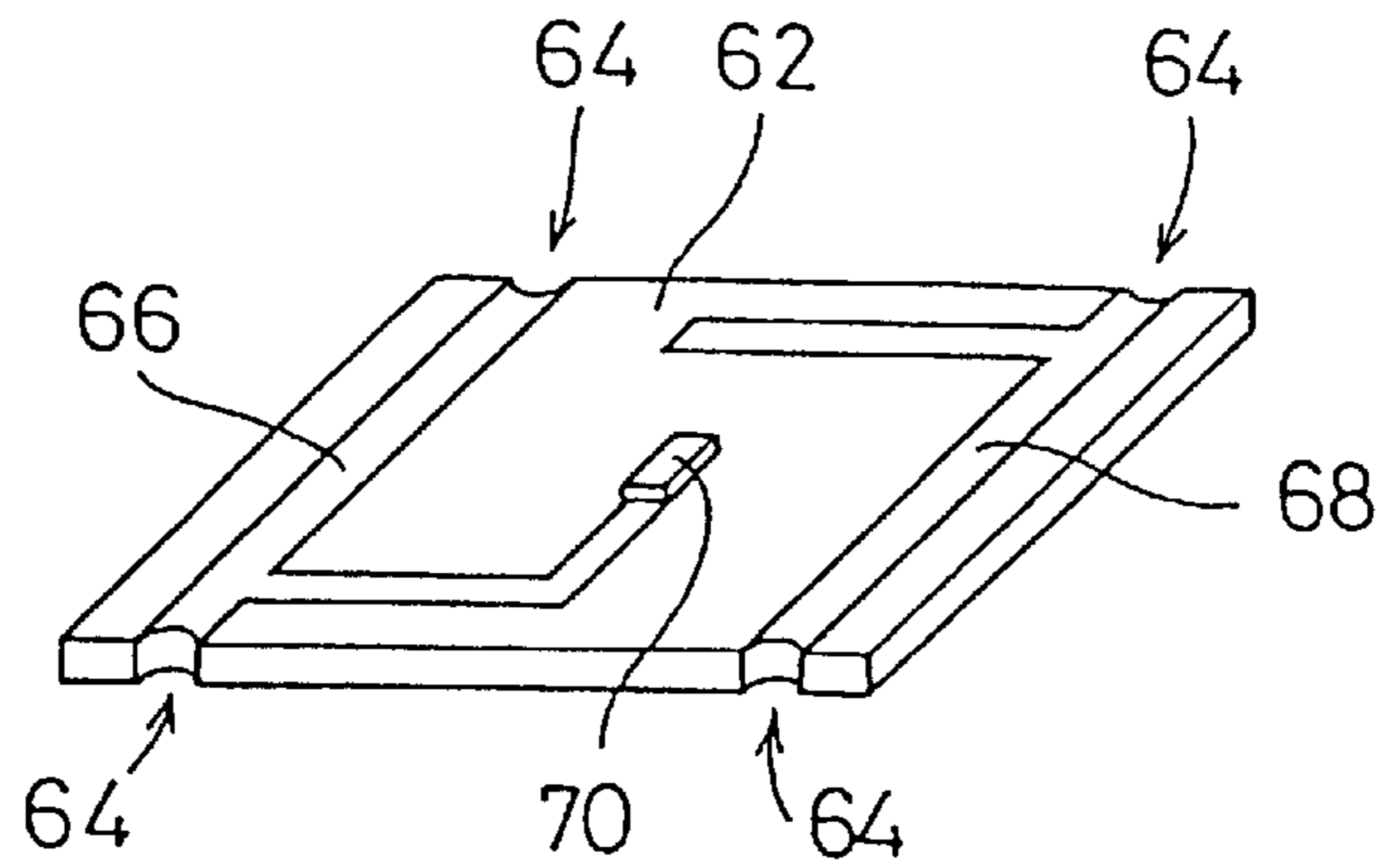


FIG. 30

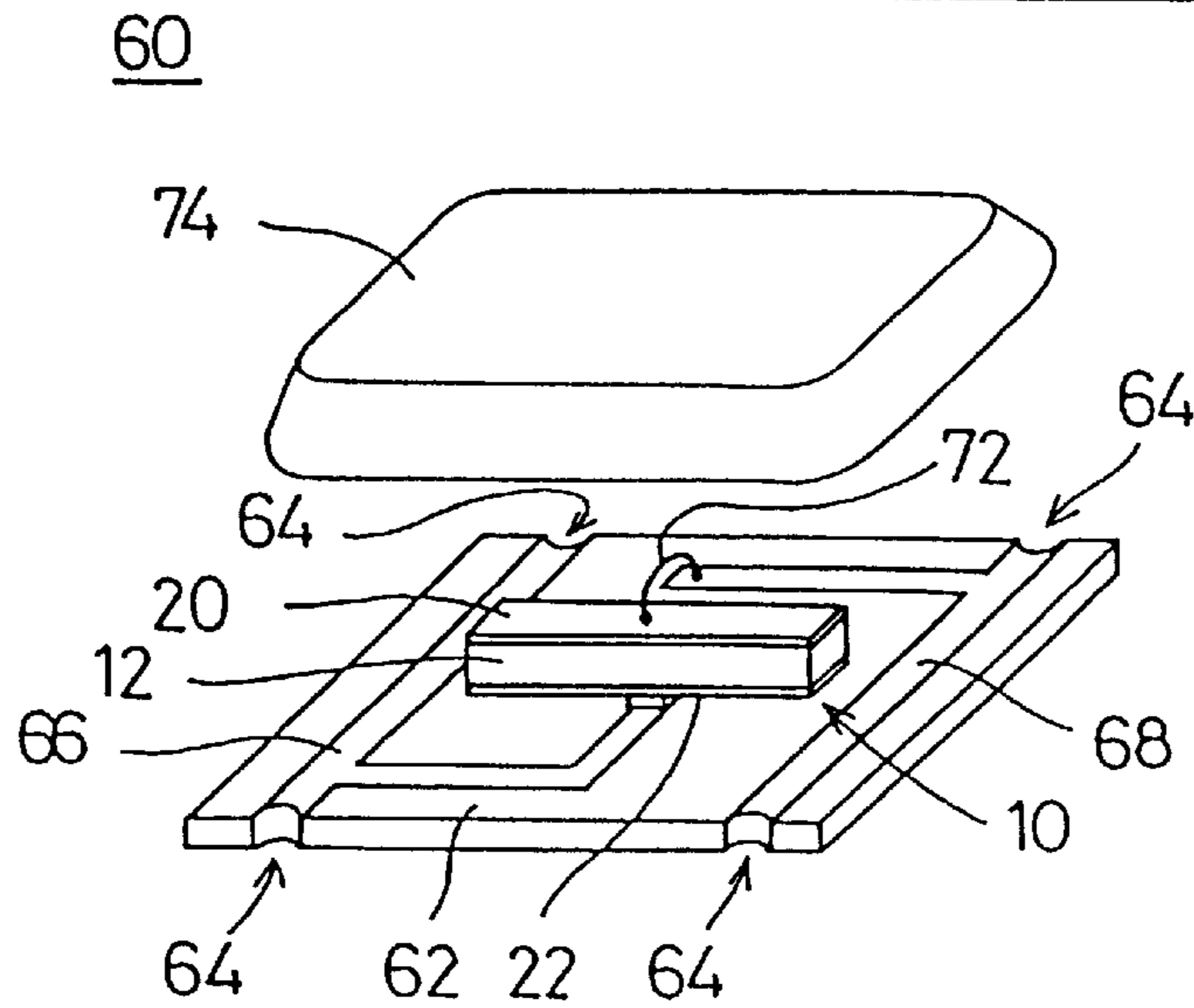


FIG. 31

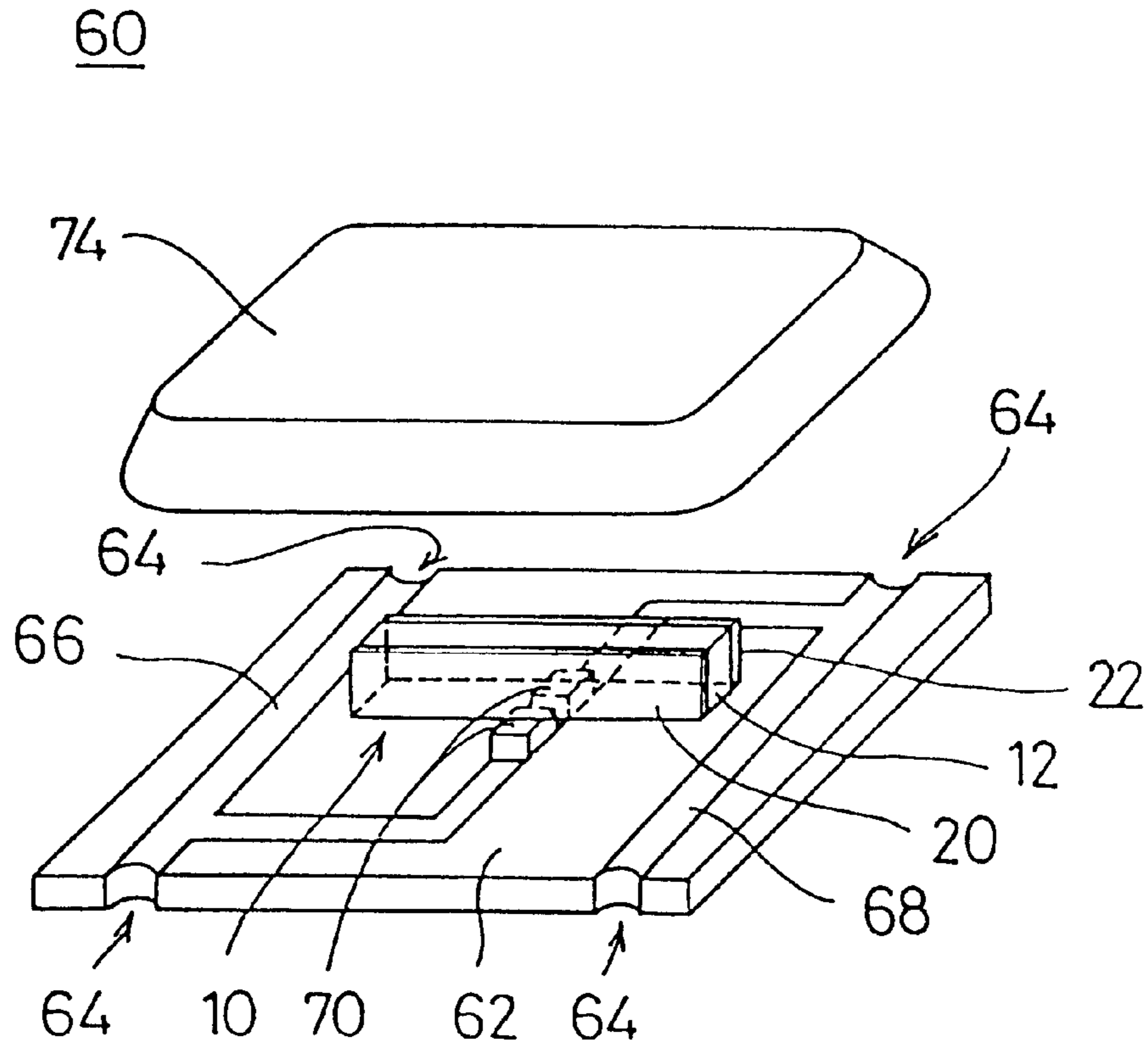


FIG. 32

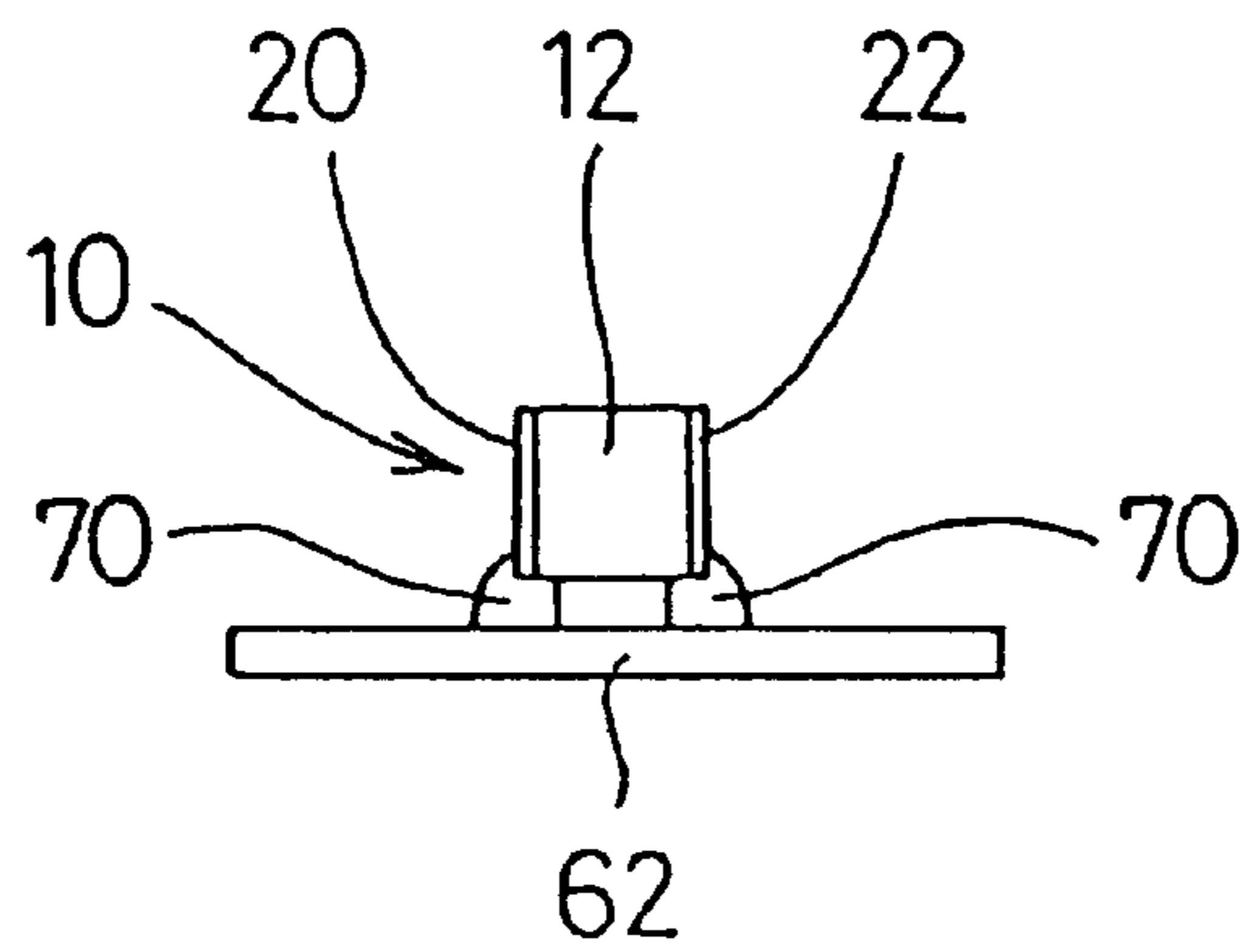


FIG. 33

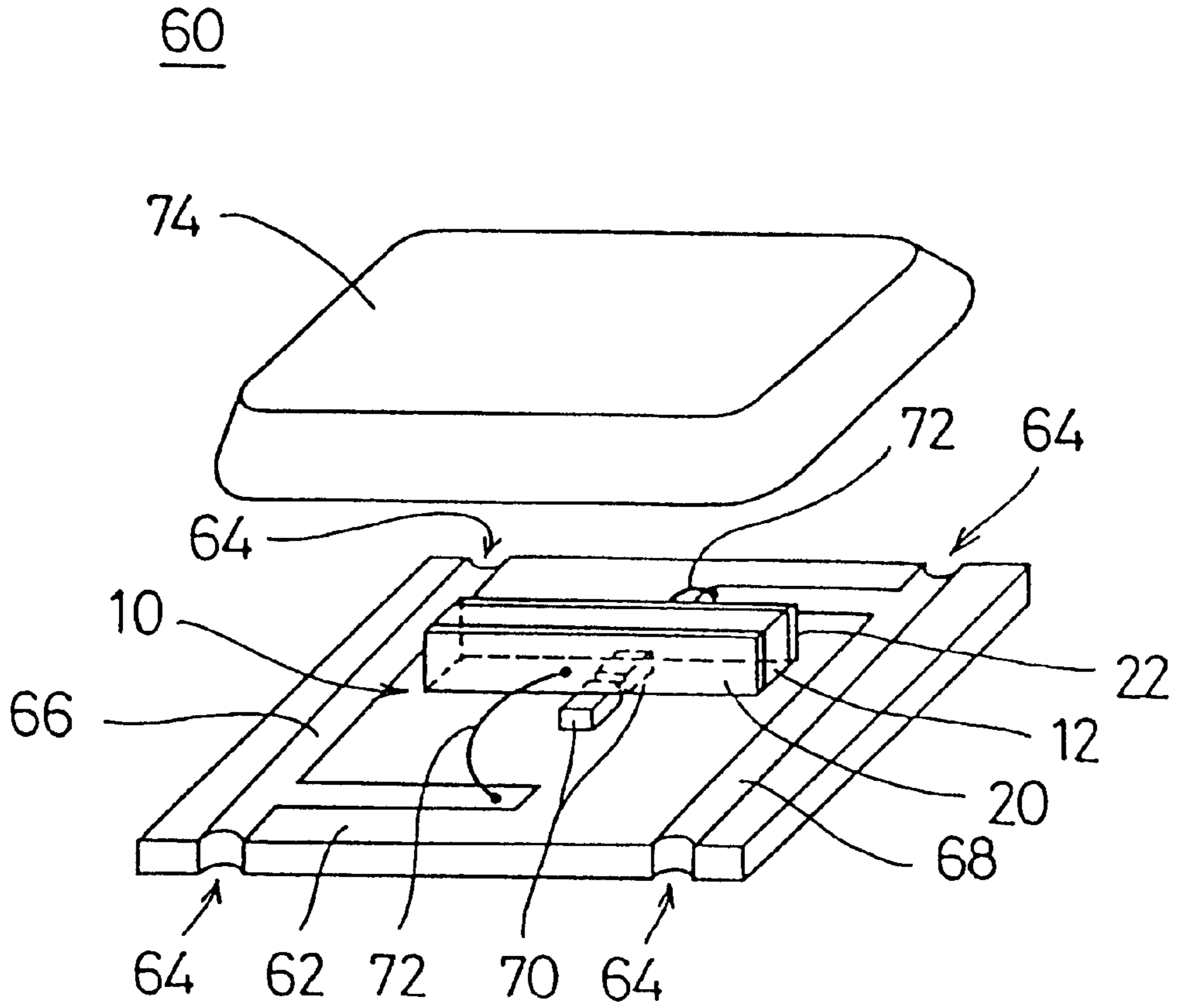


FIG. 34

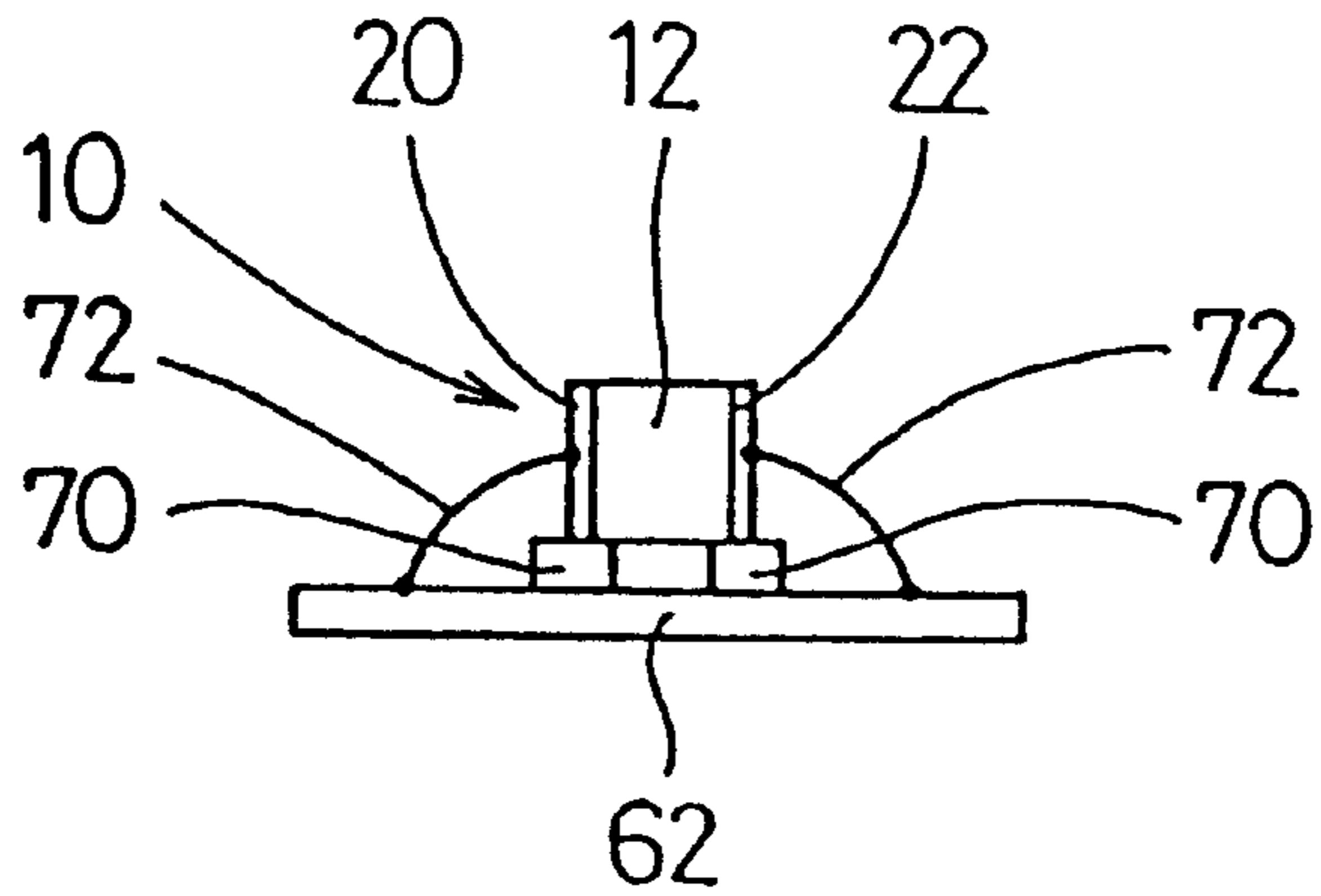


FIG. 35

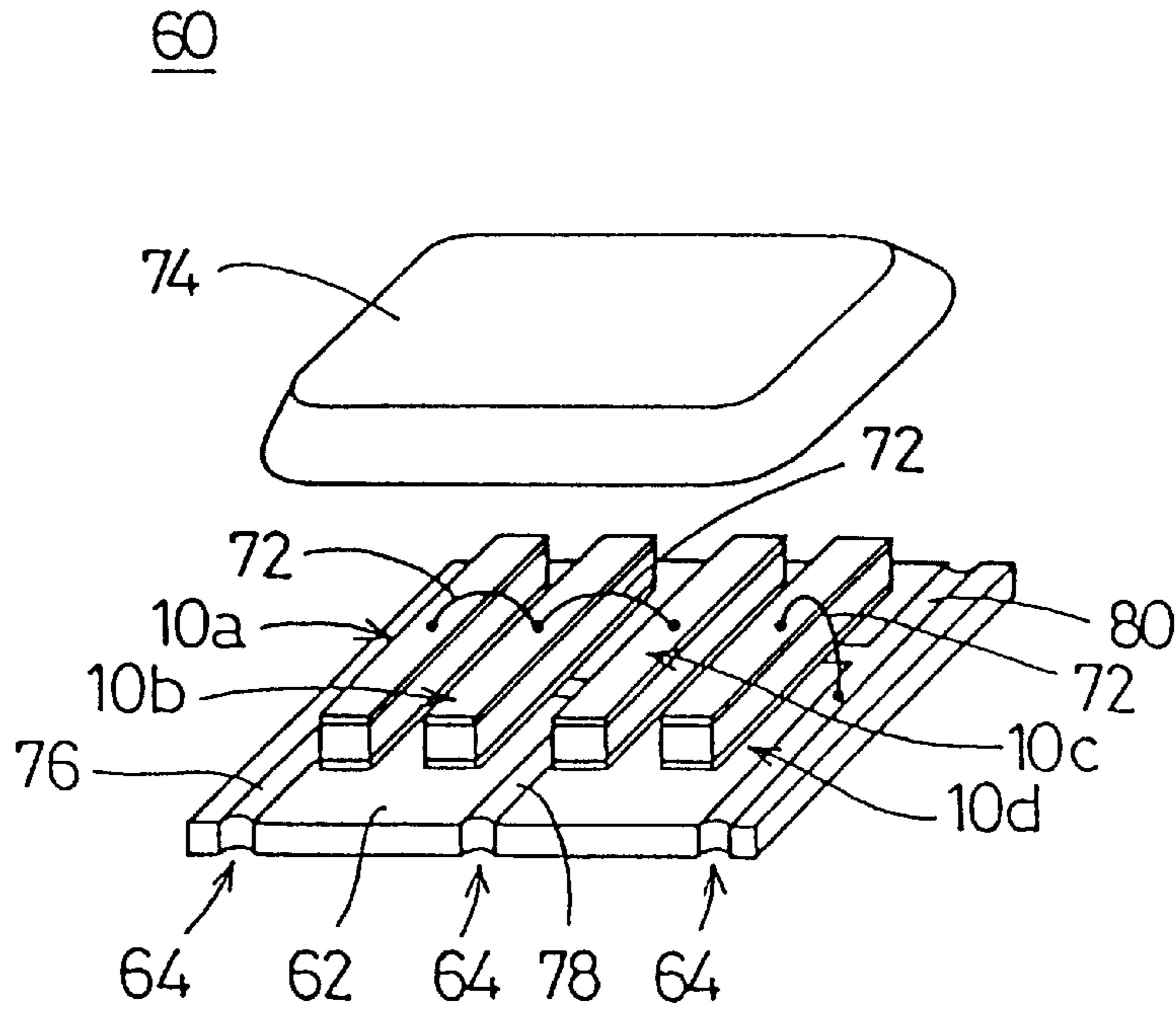


FIG. 36

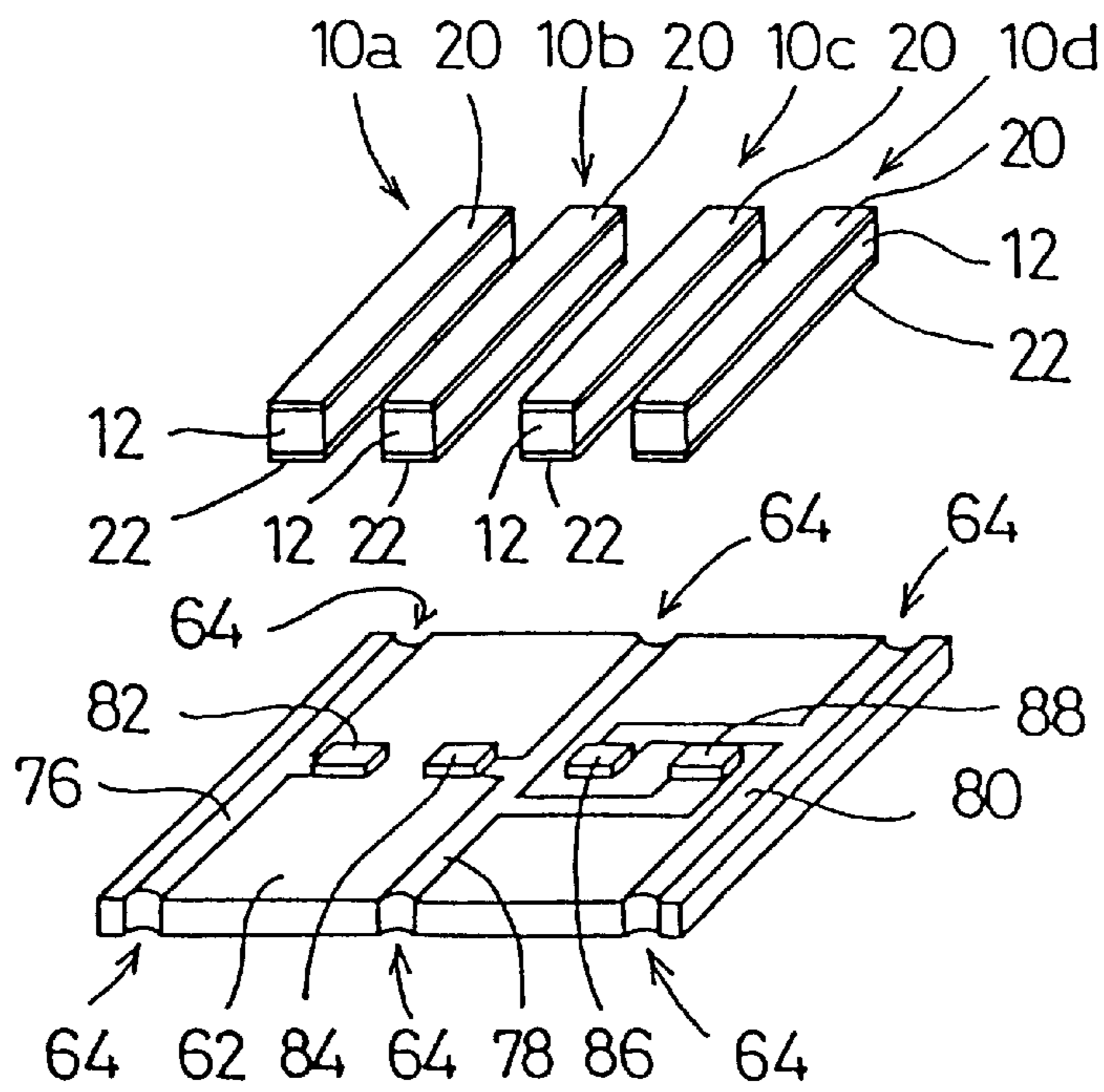


FIG. 37

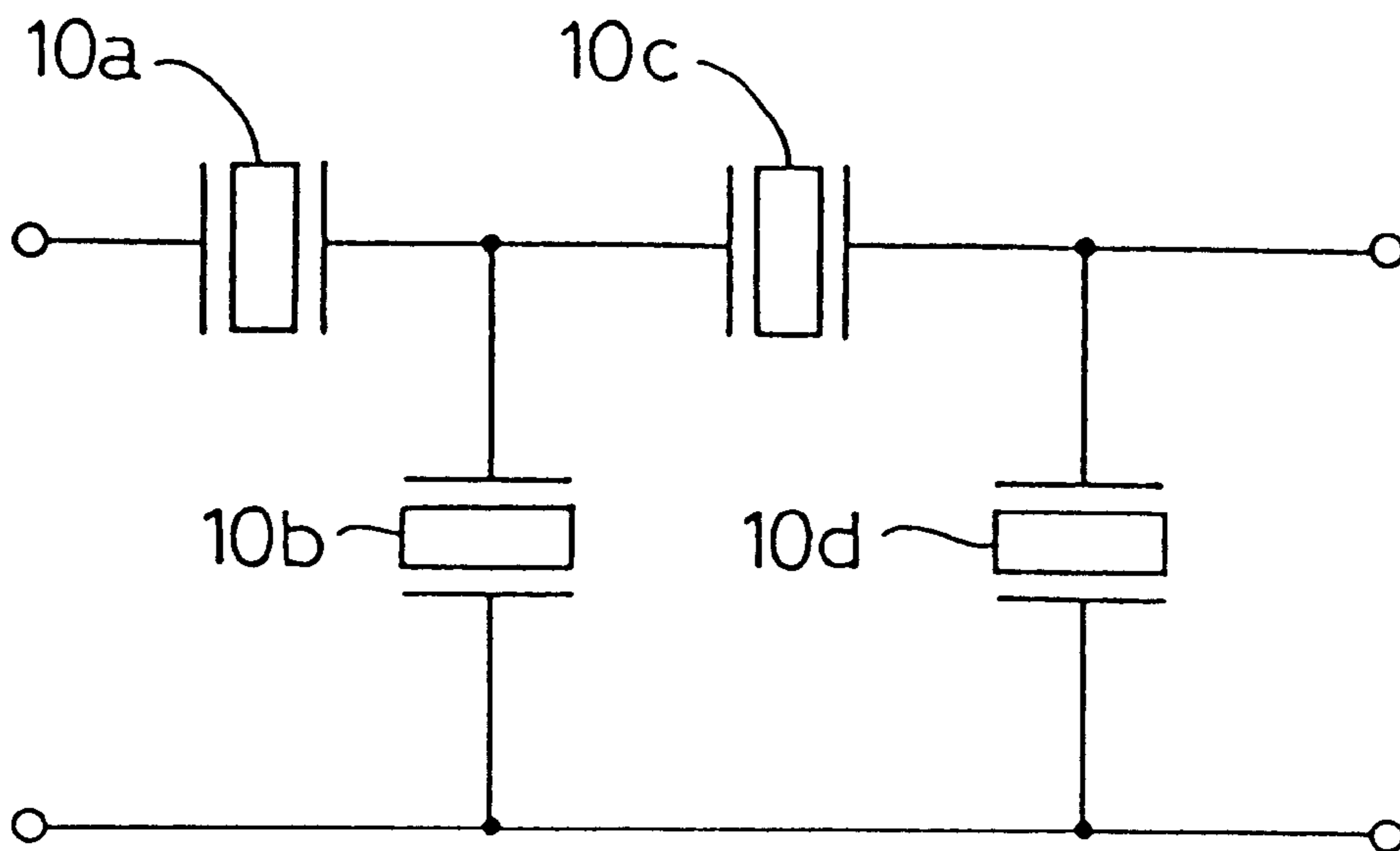


FIG. 38

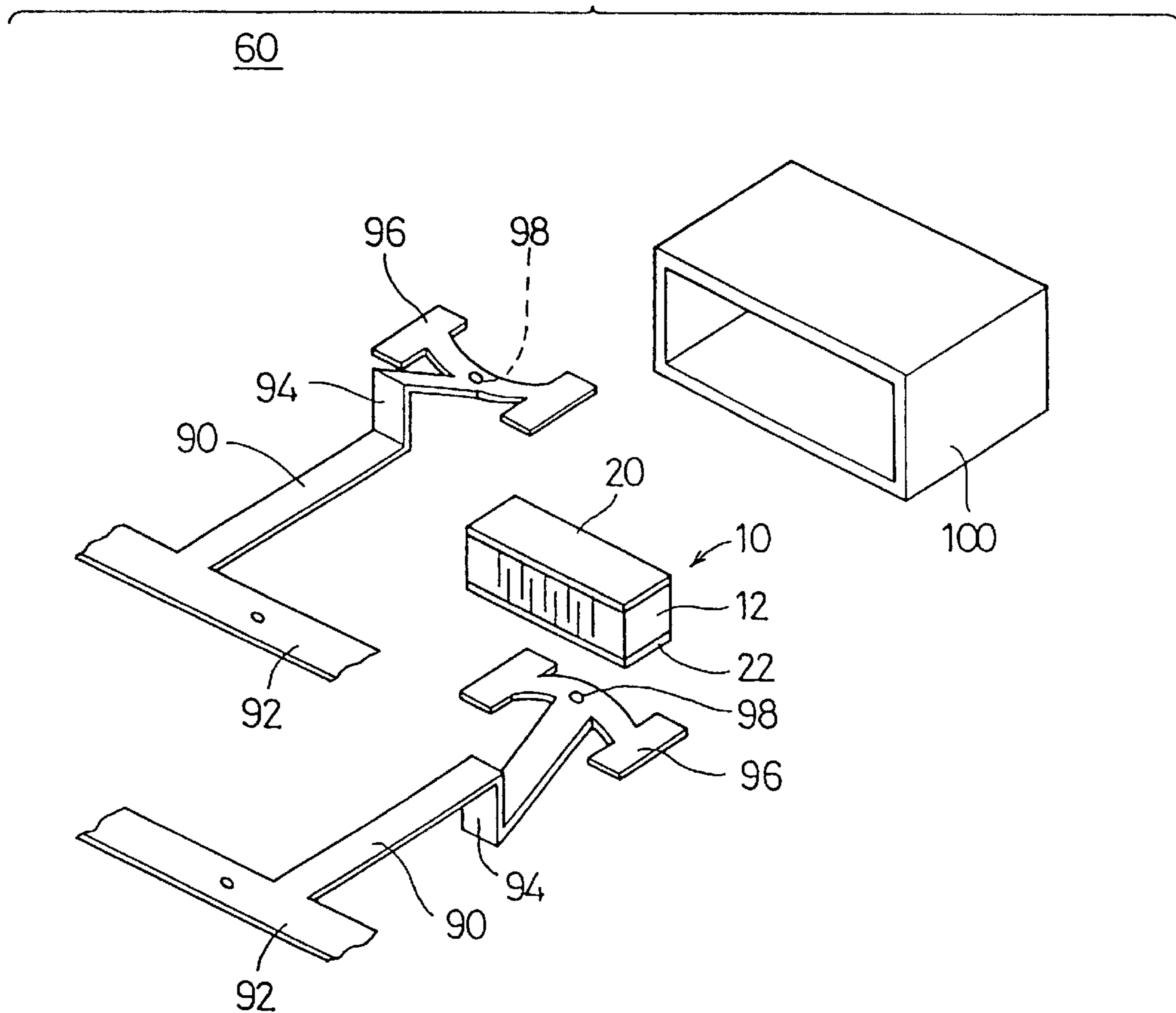


FIG. 39

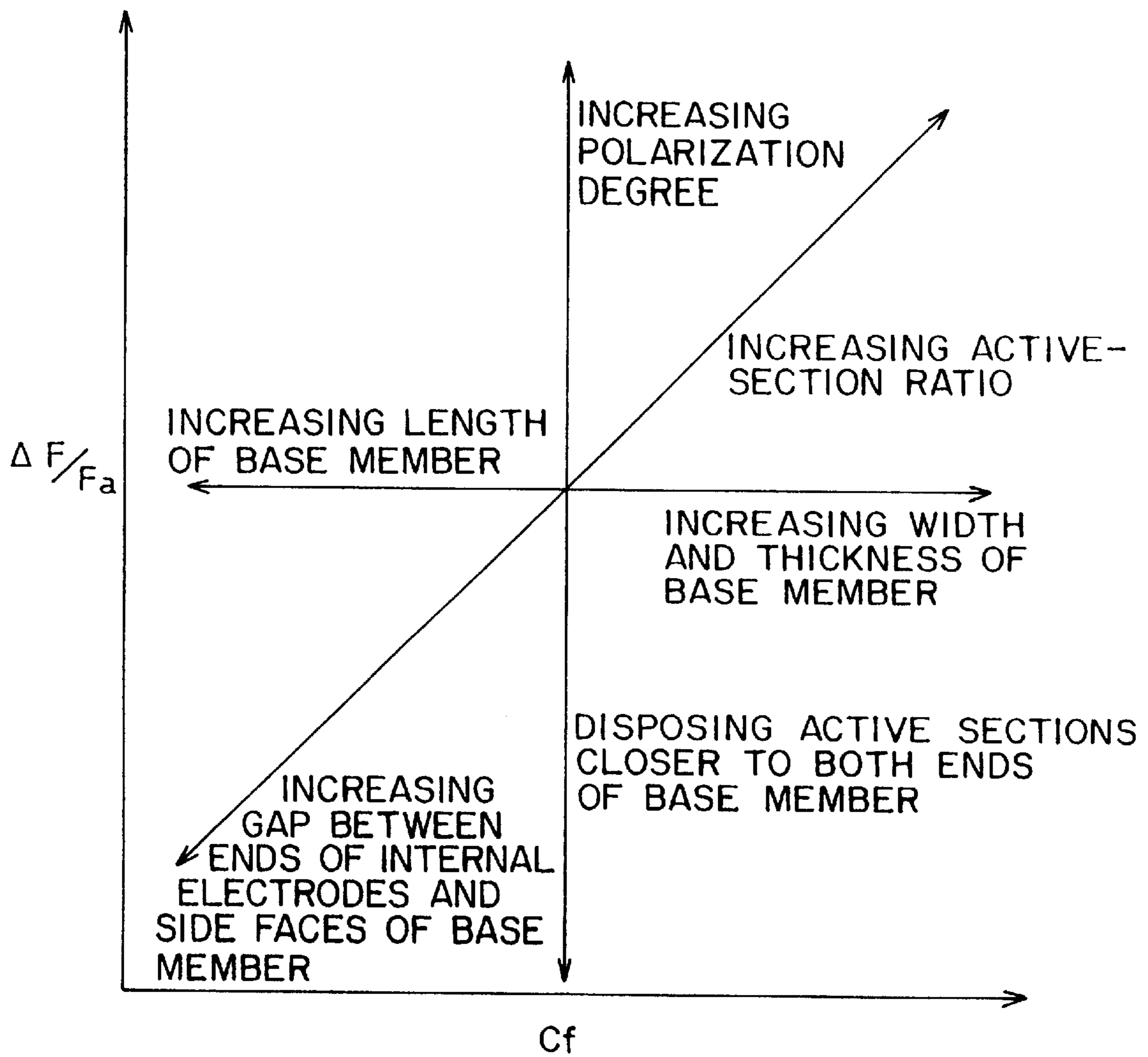


FIG. 40
PRIOR ART

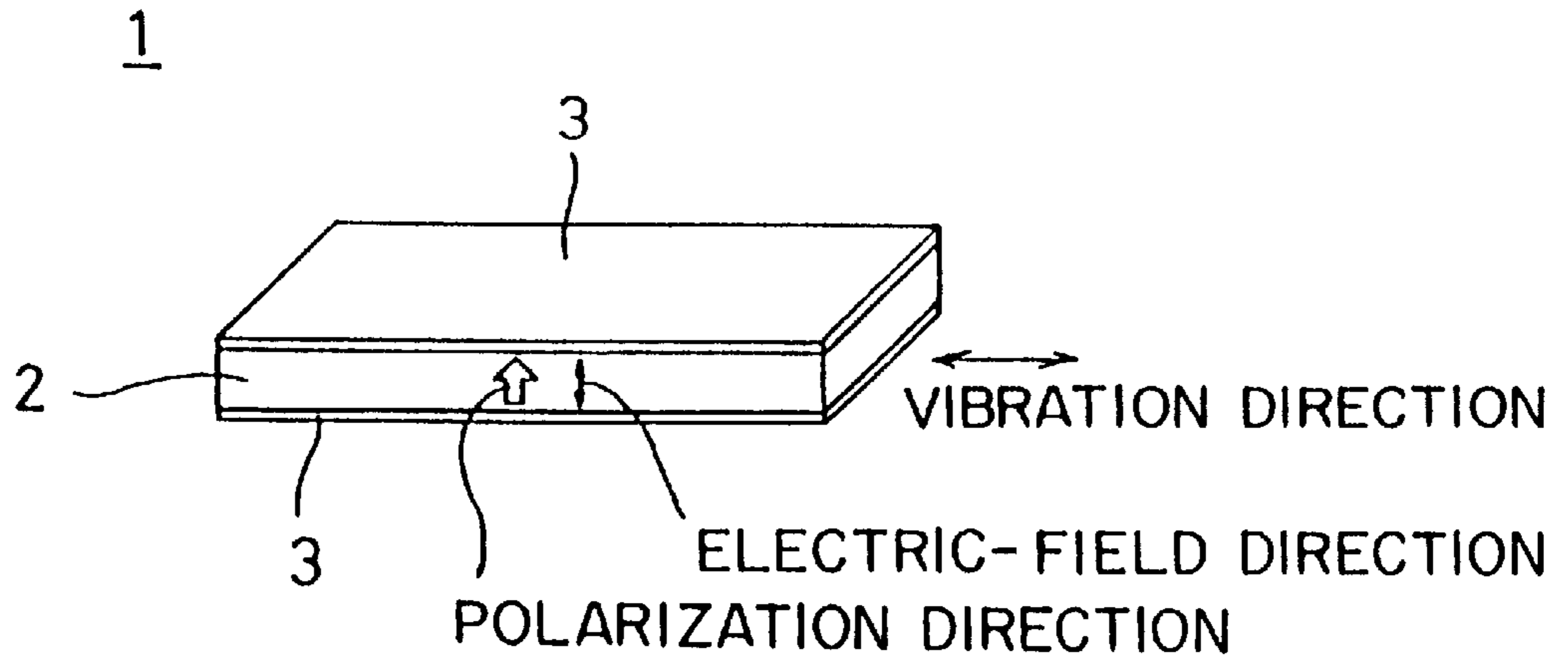
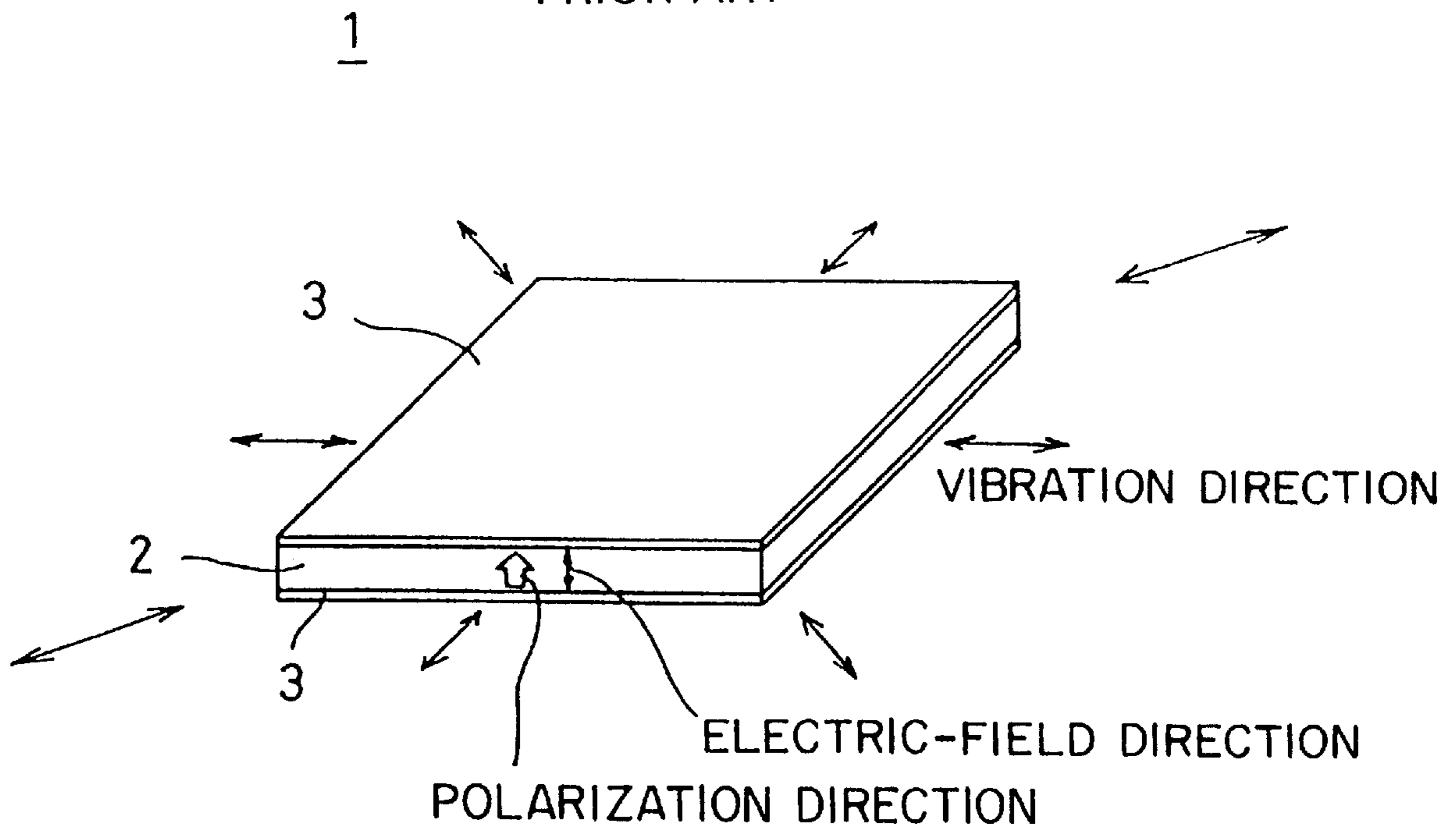


FIG. 41
PRIOR ART



PIEZOELECTRIC RESONATOR AND ELECTRONIC COMPONENT CONTAINING SAME

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to novel piezoelectric resonators and electronic components containing such novel piezoelectric resonators, and more particularly, to a novel piezoelectric resonator which maximizes the effective use of the mechanical resonance of a piezoelectric member, and electronic components containing such a novel piezoelectric resonator, such as an oscillator, a discriminator, and a filter.

2. Description of the Related Art

FIG. 40 is a perspective view of a conventional piezoelectric resonator. A piezoelectric resonator 1 includes a single piezoelectric substrate 2 having, for example, a rectangular plate shape as viewed from above. The single piezoelectric substrate 2 is polarized in the thickness direction. On two opposite major surfaces of the piezoelectric substrate 2, electrodes 3 are provided. When a signal is input between the electrodes 3, an electrical field is applied to the single piezoelectric substrate 2 in the thickness direction and the single piezoelectric substrate 2 vibrates in the longitudinal direction.

In FIG. 41, there is shown a piezoelectric resonator 1 in which electrodes 3 are provided on both surfaces of a single piezoelectric substrate 2 having a square plate shape as viewed from above. The single piezoelectric substrate 2 of the piezoelectric resonator 1 is polarized in the thickness direction. When a signal is input between the electrodes 3 in the piezoelectric resonator 1, an electrical field is applied to the single piezoelectric substrate 2 in the thickness direction and the single piezoelectric substrate 2 vibrates in square-type vibration mode (in the plane direction).

Because the piezoelectric substrate of the piezoelectric resonator shown in FIG. 40 has a rectangular plate shape, the substrate cannot be made thinner because of restrictions in strength. Therefore, the distance between the electrodes cannot be reduced and a capacitance between terminals cannot be increased. This makes it extremely difficult to achieve impedance matching with an external circuit. To form a ladder filter by alternately connecting a plurality of piezoelectric resonators in series and in parallel, the capacitance ratio of the series resonator to the parallel resonator needs to be made large in order to increase attenuation. Because a piezoelectric resonator has the shape and structural limitations described above, however, large attenuation cannot be obtained.

Such a piezoelectric resonator 1 uses the first-order resonance in the longitudinal mode. Because of its structure, the piezoelectric resonator 1 generates large spurious resonances in odd-number-order harmonic modes, such as the third-order and fifth-order modes, and in width mode. To suppress these spurious resonances, some solutions have been considered, such as polishing, increasing mass, and changing the shape of the electrode. These solutions increase manufacturing cost.

In the piezoelectric resonator shown in FIG. 41, large spurious resonances such as those in the thickness mode and in the triple-wave mode in the plane direction are generated. Since the piezoelectric resonator must have a large size as compared with a piezoelectric resonator using the longitudinal vibration in order to obtain the same resonant frequency, it is difficult to reduce the size of the piezoelectric

resonator. When a ladder filter is formed by a plurality of piezoelectric resonators, in order to increase the capacitance ratio between the series resonator and the parallel resonator, the resonators connected in series must have an increased thickness and electrodes are formed only on part of a piezoelectric substrate to make the capacitance small. In this case, since the electrodes are only partially formed, the difference ΔF between the resonant frequency and the anti-resonant frequency as well as the capacitance is reduced. The resonators connected in parallel are accordingly required to have small ΔF . As a result, the piezoelectricity of the piezoelectric substrate is not effectively used, and the transmission band width of the filter cannot be increased.

These piezoelectric resonators shown in FIGS. 40 and 41 are of unstiffened type resonators, in which the vibration direction differs from the direction of polarization and the electrical field. The electromechanical coupling coefficient of such an unstiffened piezoelectric resonator is lower than that of a stiffened piezoelectric resonator, in which the vibration direction, the direction of polarization, and the direction in which an electrical field is applied are the same.

An unstiffened piezoelectric resonator has a relatively small frequency difference ΔF between the resonant frequency and the antiresonant frequency. This leads to a drawback in which a frequency-band width in use is narrow when an unstiffened frequency resonator is used as an oscillator or a filter. Therefore, the degree of flexibility and freedom in resonator characteristics design is low in such unstiffened piezoelectric resonators and electronic components containing such piezoelectric resonators.

In the prior art, such as U.S. Pat. No. 5,250,868, a piezoelectric effect device includes a sintered stack of piezoelectric elements which stack is completely enclosed in a flexible metal housing to be used as an actuator. The stack includes non-active portions I_1 and I_n located at the ends of the stack for protecting the active portions I_2 through I_{n-1} . In order to function as an actuator, the stack 3 of piezoelectric elements must be supported at one end and must be free to vibrate in a longitudinal mode at the other end. Thus, the stack 3 could not be supported at a point other than the one end and therefore, the stack 3 could not be supported at a central or middle portion of the stack 3 without destroying the operability of the stack 3 as an actuator. In addition, the stack 3 of piezoelectric elements must achieve maximum displacement required for actuators and therefore, the stack 3 must have a node point located only at the supported end of the stack 3. The stack 3 cannot have a node point located at a central or middle portion of the stack, otherwise the stack 3 could not function as an actuator. By arranging the stack 3 to have a node point at one end and to be supported at the same end, the stack 3 can achieve the maximum desired displacement necessary in an actuator.

In addition, U.S. Pat. No. 4,633,120 teaches an electrostriction transducer including a plurality of electrostriction layers, not piezoelectric layers, stacked on each other and including protection or dummy layers on each end of the stack of electrostriction layers for protecting the stack of electrostrictive layers. The electrostriction layers are very different from piezoelectric elements and cannot function in the same manner as piezoelectric elements, as is well known.

The prior art stacked devices are only adapted to function as an actuator or electrostrictive transducer, and could not function as a resonator. Therefore, a location of a resonant point and an anti-resonant point and an amount of capacitance is of no concern in these types of devices. Accordingly,

the prior art stacked devices have electrodes provided at both ends of the stack of piezoelectric or electrostriction members. These electrodes cannot be located along a longitudinal side edge of the stack in order for the stacked devices to function as an actuator or transducer. Furthermore, these prior art devices cannot have a node located at a central or middle portion of a stack of piezoelectric elements or be supported at a node located at a central or middle portion of the stack.

In addition, the only purpose for providing the protection or dummy layer is to protect the piezoelectric or electrostriction layers surrounded by the protection or dummy layers. The stacked piezoelectric or electrostrictive layers of the prior art are not arranged or adapted to function as a resonator which can be used in an oscillator, a discriminator, or a filter.

SUMMARY OF THE INVENTION

The preferred embodiments of the present invention provide a piezoelectric resonator having a small spurious resonance, a large difference ΔF between the resonant frequency and the antiresonant frequency, an easily adjustable location of a resonant point and an antiresonant point, an easily adjustable capacitance and ΔF , and a large degree of freedom and flexibility in resonator characteristics design, and also provide an electronic component containing such a novel piezoelectric resonator.

The preferred embodiments of the present invention also provide a piezoelectric resonator including a piezoelectric base member comprises an integral unit including a plurality of interconnected piezoelectric layers or members and a plurality of electrodes disposed between said piezoelectric layers.

The preferred embodiments of the present invention also provide a piezoelectric resonator including a piezoelectric base member comprising a stack of a plurality of interconnected piezoelectric layers each of which is adapted to vibrate individually in a thickness vibration mode such that the stack of interconnected piezoelectric layers vibrate as a whole in a longitudinal vibration mode.

The preferred embodiments of the present invention further provide a piezoelectric resonator including a piezoelectric base member comprises an integral unit including a plurality of interconnected piezoelectric layers or members and a plurality of electrodes disposed between said piezoelectric layers, wherein each of the piezoelectric layers located between adjacent ones of the electrodes is polarized in a direction that is opposite to a direction of polarization of at least one adjacent piezoelectric layer. That is, the base member is preferably polarized in opposite directions at both sides of at least one of the electrodes.

According to one preferred embodiment of the present invention, a piezoelectric resonator comprises a base member; a plurality of internal electrodes disposed in the base member so as to be substantially perpendicular to a longitudinal direction of the base member; and one pair of external electrodes provided on a common side surface or different side surfaces of the base member to connect the plurality of internal electrodes; wherein the base member includes an integral unit including a plurality of piezoelectric layers and the plurality of internal electrodes which are alternately laminated, and an AC electric field is applied to each of the piezoelectric layers via the plurality of internal electrodes such that the base member generates longitudinal basic vibration.

The piezoelectric resonator according to the preferred embodiments of the present invention may be configured

such that the plurality of piezoelectric layers are polarized in the longitudinal direction of the base member in opposite directions at each side of each of the plurality of internal electrodes, and adjacent electrodes of the plurality of internal electrodes are alternately connected to one of the external electrodes, respectively.

The piezoelectric resonator may be configured such that it further includes at least one pair of connection sections in which alternate exposed sections of the plurality of internal electrodes are covered by insulating films, each of the plurality of internal electrodes is formed to cover an entire surface of a cross section of the base member, and the one pair of external electrodes is disposed on the one pair of connection sections such that adjacent internal electrodes among the plurality of internal electrodes are alternately connected to one of the pair of external electrodes, respectively.

The piezoelectric resonator may also be configured such that a part of each of the plurality of internal electrodes is arranged so as not to be exposed at side surfaces of the base member, and the exposed sections of the plurality of internal electrodes are connected to the one pair of external electrodes such that adjacent internal electrodes among the plurality of internal electrodes are alternately connected to one of the pair of external electrodes, respectively.

The piezoelectric resonator may also be configured such that the base member is provided with at least either an inactive section which is not polarized or an inactive section to which no electric field has been applied.

In a preferred embodiment, an active section constitutes a central portion of the piezoelectric base member and there are two inactive sections each provided at one of the ends of the active section such that the active section is surrounded by inactive sections at opposite ends thereof. The piezoelectric base member is preferably arranged such that a node is defined at a center or midpoint of the active section thereby allowing the piezoelectric resonator to be supported at the node without affecting the resonator characteristics.

The inactive section may be formed in many ways. First, the inactive section may be formed without an electrode material disposed thereon. As a result, the inactive section without an electrode cannot be polarized or receive an electric field. Alternatively, the inactive section may be provided with an electrode material but the inactive section is not polarized so it does not generate vibration, and is therefore inactive.

Although one or more inactive sections may be disposed at any location within the base member, it is preferred in the piezoelectric resonator of the preferred embodiments of the present invention that the inactive section be provided at the two opposite ends of the active section, and the active section preferably occupies about 50% of a length of the base member.

The piezoelectric resonator may further include a support member, and a mounting member disposed between the support member and preferably an approximate center section of the base member.

Another preferred embodiment of the present invention provides an electronic component containing the above-described piezoelectric resonator, wherein the support member comprises an insulating substrate on which a pattern electrode is provided; the base member is mounted on the insulating substrate via the mounting member; and a cap is preferably disposed on the insulating substrate so as to cover the base member.

Another preferred embodiment of the present invention provides an electronic component containing the above-

described piezoelectric resonator, wherein the support member comprises an insulating substrate on which a pattern electrode is provided; a plurality of base members are mounted on the insulating substrate via the mounting member so as to define a ladder filter; and a cap is preferably disposed on the insulating substrate so as to cover the base member.

As a result of the structure and novel arrangement of the piezoelectric resonator according to the preferred embodiments of the present invention having a base member comprising piezoelectric layers and electrodes which are alternately laminated, the capacitance of the piezoelectric resonator can be easily changed by adjusting the intervals, the sizes, or the number of electrodes used for applying an electric field to the base member. When such a piezoelectric resonator is constructed such that the vibration direction, the direction of polarization, and the direction in which an electrical field is applied are the same in the piezoelectric layers, the resonator is a stiffened type resonator. Therefore, as compared with an unstiffened piezoelectric resonator, in which the vibration direction differs from the direction of polarization and electrical field, the stiffened piezoelectric resonator has a larger electromechanical coupling coefficient and a larger frequency difference ΔF between the resonant frequency and the antiresonant frequency. In addition, vibrations in modes such as the width and thickness modes, which are different from the longitudinal basic vibration, are unlikely to occur in a stiffened piezoelectric resonator. Furthermore, the frequency difference ΔF and the resonant frequency can be easily adjusted by reducing or increasing a size or mass of an inactive section.

When electronic components such as an oscillator, a discriminator, and a filter are constructed to include the piezoelectric resonator according to the preferred embodiments of the present invention, the piezoelectric resonator is preferably mounted on an insulating substrate on which pattern electrodes are provided and the resonator is preferably covered by a cap to form chip-type, surface-mountable electronic components.

According to the preferred embodiments of the present invention, since the capacitance of the piezoelectric resonator can be easily adjusted, it is easy to achieve impedance matching with an external circuit when the piezoelectric resonator is mounted on a circuit board. When the piezoelectric resonator is a stiffened type resonator, the frequency difference ΔF between the resonant frequency and the antiresonant frequency is large as compared with a conventional piezoelectric resonator, and thus a wide-frequency-band resonator is obtained. In addition, vibrations in modes other than the basic-vibration mode are unlikely to occur in this piezoelectric resonator, and superior resonator characteristics are achieved. Since the frequency difference ΔF is easily adjusted by adjusting the inactive section, the frequency-band width of the piezoelectric resonator can easily be changed.

Since a chip-type electronic component can be constructed using the piezoelectric resonator of the preferred embodiments of the present invention, it is easy to mount the component on a circuit board. It is also easy to achieve impedance matching between such an electronic component and an external circuit by adjusting the capacitance of the piezoelectric resonator. In addition, in a ladder filter formed by alternately connecting a plurality of piezoelectric resonators in series and in parallel, attenuation in the filter can be adjusted by changing the ratio of the capacitance of the piezoelectric resonator connected in series to that of the piezoelectric resonator connected in parallel.

These and other elements, features, and advantages of the preferred embodiments of the present invention will be apparent from the following detailed description of the preferred embodiments of the present invention, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective view of a piezoelectric resonator according to a preferred embodiment of the present invention.

FIG. 2 is a view showing the structure of the piezoelectric resonator shown in FIG. 1.

FIG. 3 is a perspective view indicating how ceramic green sheets are laminated in order to produce the piezoelectric resonator shown in FIG. 1.

FIG. 4 is a view showing a laminated block formed by the ceramic green sheets shown in FIG. 3.

FIG. 5 is a view showing portions where the laminated block shown in FIG. 4 is cut.

FIG. 6 is a view showing a plate-shaped block made by cutting the laminated block shown in FIG. 5.

FIG. 7 is a view showing the condition in which a resin insulating material is applied to the plate-shaped block shown in FIG. 6 and external electrodes are formed.

FIG. 8 is a perspective view of an unstiffened piezoelectric resonator which vibrates in the longitudinal direction, which is shown for comparison.

FIG. 9 is a perspective view of a stiffened piezoelectric resonator which vibrates in the longitudinal direction.

FIG. 10 is a perspective view of an unstiffened piezoelectric resonator which vibrates in the plane direction (square-type vibration), which is shown for comparison.

FIG. 11 is a view showing another piezoelectric resonator according to the preferred embodiments of the present invention.

FIG. 12 is a view showing still another piezoelectric resonator according to the preferred embodiments of the present invention.

FIG. 13 is a chart showing the relationship between the frequency and the impedance of the piezoelectric resonator according to the preferred embodiments of the present invention.

FIG. 14 is a chart showing the relationship between the frequency and the impedance of a conventional piezoelectric resonator.

FIG. 15 is a view of a piezoelectric resonator in which the distribution of an active section and inactive sections is changed in a base member.

FIG. 16 is a chart indicating the relationship between the distribution of an active section and capacitance, and $\Delta F/F_a$.

FIG. 17 is a chart showing the relationship between an active-section ratio and ΔF .

FIG. 18 is a view showing a modified piezoelectric resonator according to the preferred embodiments of the present invention.

FIG. 19 is a view showing another modified piezoelectric resonator according to the preferred embodiments of the present invention.

FIG. 20 is a view showing still another piezoelectric resonator according to the preferred embodiments of the present invention.

FIG. 21 is a view indicating the gap between the end of an internal electrode and a side surface of a base member in the piezoelectric resonator.

FIG. 22 is a chart indicating the relationships between the capacitance and ΔF , and the gap between an internal electrode and a side surface of the base member.

FIG. 23 is a plan showing modified piezoelectric layers of the piezoelectric resonator shown in FIG. 20.

FIG. 24 is a view showing a piezoelectric resonator having the piezoelectric layers shown in FIG. 23.

FIG. 25 is a view showing a modified inactive section of a piezoelectric resonator.

FIG. 26 is a view showing another modified inactive section of a piezoelectric resonator.

FIG. 27 is a view showing an electrode formed at an end of a base member.

FIG. 28 is a perspective view of an electronic component containing the above-described piezoelectric resonator.

FIG. 29 is a perspective view of an insulating substrate provided in the electronic component shown in FIG. 28.

FIG. 30 is an exploded perspective view of the electronic component shown in FIG. 28.

FIG. 31 is a view indicating another method for mounting the piezoelectric resonator on the insulating substrate.

FIG. 32 is a side view showing the method for mounting the piezoelectric resonator, shown in FIG. 31.

FIG. 33 is a view indicating still another method for mounting the piezoelectric resonator on the insulating substrate.

FIG. 34 is a side view showing the method for mounting the piezoelectric resonator, shown in FIG. 33.

FIG. 35 is an exploded perspective view of a ladder filter using the piezoelectric resonators according to the preferred embodiments of the present invention.

FIG. 36 is a perspective view of an insulating substrate and the piezoelectric resonators in the ladder filter shown in FIG. 35.

FIG. 37 is an equivalent circuit diagram of the ladder filter shown in FIG. 35.

FIG. 38 is an exploded perspective view of a two-terminal electronic component.

FIG. 39 is a chart indicating the relationship between C_f and $\Delta F/F_a$, and other parameters.

FIG. 40 is a view of a conventional unstiffened piezoelectric resonator.

FIG. 41 is a view of another conventional unstiffened piezoelectric resonator.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

FIG. 1 is a perspective view of a piezoelectric resonator according to a preferred embodiment of the present invention. FIG. 2 shows the internal structure of the piezoelectric resonator. The piezoelectric resonator 10 includes a base member 12 preferably having, for example, a substantially rectangular-parallelepiped shape. The base member 12 is made from, for example, a piezoelectric ceramic material. A plurality of electrodes 14 are provided in the base member 12 and preferably at both end surfaces of the base member 12 in the longitudinal direction such that the surfaces of the electrodes 14 are substantially perpendicular to the longitudinal direction of the base member 12. The base member 12 is preferably polarized in opposite directions at both sides of at least one of the electrodes 14 as seen in FIG. 2.

On the opposing side surfaces of the base member 12, a plurality of insulating films 16 and 18 are provided, respec-

tively. On a first side surface of the base member 12, the insulating film 16 covers the exposed section of every other electrode 14. On a second side surface of the base member 12, the insulating film 18 covers the exposed section of every other electrode 14 not covered by the insulating film 16 on the first side surface. The side surfaces of the base member 12 on which the insulating films 16 and 18 are provided serve as connection sections to external electrodes, which will be described later.

In these connection sections, namely, the side surfaces of the base member 12 on which the insulating films 16 and 18 are provided, external electrodes 20 and 22 are disposed. The electrode 20 connects to electrodes 14 which are not covered by the insulating film 16, and the electrode 22 connects to electrodes 14 which are not covered by the insulating film 18. In other words, two adjacent electrodes 14 are connected to the electrodes 20 and 22, respectively. The piezoelectric resonator 10 preferably uses the external electrodes 20 and 22 as input and output electrodes. The base member 12 is piezoelectrically active because an electric field is applied between adjacent electrodes 14.

In a preferred embodiment of making the piezoelectric resonator 10, green sheets 30 made from piezoelectric ceramic are first prepared as shown in FIG. 3. On one surface of each green sheet 30, electrically conductive paste including, for example, silver, palladium, and an organic binder, is applied to form an electrically conductive paste layer 32 over almost the entire area of each green sheet 30 excluding an end portion. A plurality of green sheets 30 is laminated such that the end portions where the electrically conductive paste layers 32 are not formed on the green sheets are placed alternately in opposite directions. The laminated member with electrically conductive paste applied to opposite side faces is baked to form a laminated block 34 shown in FIG. 4.

A plurality of electrodes 36, which have been made by baking the electrically conductive layers 32, are formed in and at both ends of the laminated block 34. External electrodes 38 and 40 disposed on opposite side surfaces are connected to every other electrode 36, respectively, since the electrodes 36 are alternately exposed on opposite side surfaces of the laminated block 34. When a DC voltage is applied to the external electrodes 38 and 40, the laminated block 34 is polarized. Inside the laminated block 34, a high DC electric field is applied between adjacent internal electrodes 36 alternately in opposite directions. Therefore, the laminated block 34 is polarized in the opposite directions at both sides of the electrodes 36 as shown by arrows in FIG. 4.

The laminated block 34 preferably is surface-ground to the desired thickness since the antiresonant frequency of the resonator is determined by the thickness of the laminated block 34. The laminated block 34 is cut by a dicing machine along dotted lines shown in FIG. 5 such that the cutting planes are substantially perpendicular to the plurality of electrodes 36. Then, a plate-shaped block 42 shown in FIG. 6 is obtained. A resin insulating material 44 is preferably applied to both surfaces of the plate-shaped block 42 as shown in FIG. 7 such that the material 44 is applied to every other internal electrode 36 on one surface and every other electrode 36 to which the material 44 is not applied, on the other surface. External electrodes 48 are disposed on the plate-shaped block 42. Then, the resultant block is cut substantially perpendicularly to the internal electrodes 36 to form the piezoelectric resonator 10 shown in FIG. 1.

When a signal is applied to the external electrodes 20 and 22 in the piezoelectric resonator 10, since voltages are

applied in directions opposite to the directions of polarization of the piezoelectric layers in the base member **12** which are polarized, the piezoelectric layers simultaneously expand and contract as an integral unit in the same direction. An AC electric field is preferably applied to each piezoelectric layer in the longitudinal direction of the base member **12** via the electrodes **14** connected to the external electrodes **20** and **22**, and a driving force for expansion and contraction is generated at each piezoelectric layer. Therefore, the piezoelectric resonator **10** is constructed and arranged to vibrate in the longitudinal direction in a basic longitudinal vibration mode with the approximate center of the base member **12** serving as a node.

As a result of the piezoelectric resonator **10** according to the preferred embodiments of the present invention having a structure in which a plurality of piezoelectric layers and electrodes are alternately laminated, the capacitance of the piezoelectric resonator **10** can be easily changed by adjusting the number of the laminated layers, the electrode size, or the distances between the electrodes. Therefore, it is easy to achieve impedance matching with an external circuit when the piezoelectric resonator **10** is mounted on a circuit board.

In the piezoelectric resonator **10** shown in FIG. **1**, the polarization direction of the base member **12**, the applied electric field direction, and the direction of vibration in the base member **12** are all the same. In other words, the piezoelectric resonator **10** is a stiffened type resonator. The stiffened piezoelectric resonator **10** has a larger electromagnetic coupling coefficient than an unstiffened piezoelectric resonator, in which the direction of vibration differs from the direction of polarization and electric field. Therefore, the piezoelectric resonator **10** has a larger frequency difference ΔF between the resonant frequency and the antiresonant frequency than the conventional piezoelectric resonator. As a result of this unique structure, the piezoelectric resonator **10** achieves wide-frequency-band characteristics.

To measure differences between stiffened and unstiffened piezoelectric resonators, piezoelectric resonators shown in FIGS. **8**, **9** and **10** were made. The piezoelectric resonator shown

in FIG. **8** was made by forming electrodes on both surfaces in the thickness direction of a piezoelectric substrate measuring approximately 4.0 mm by 1.0 mm by 0.38 mm. This piezoelectric resonator was polarized in the thickness direction and vibrated in the longitudinal direction when a signal was applied to the electrodes. The piezoelectric resonator shown in FIG. **9** had the same dimensions as the piezoelectric resonator shown in FIG. **8**. Electrodes were disposed on both surfaces in the longitudinal direction of a piezoelectric substrate. The piezoelectric resonator was polarized in the longitudinal direction and vibrated in the longitudinal direction when a signal was applied to the electrodes. The piezoelectric resonator shown in FIG. **10** was made by disposing electrodes on both surfaces in the thickness direction of a piezoelectric substrate measuring approximately 4.7 mm by 4.7 mm by 0.38 mm. This piezoelectric resonator was polarized in the thickness direction and vibrated in the plane direction when a signal was applied to the electrodes. The piezoelectric resonators shown in FIGS. **8** and **10** were unstiffened type resonators and the piezoelectric resonator shown in FIG. **9** was a stiffened type resonator.

The resonant frequency F_r and the electromechanical coupling coefficient K of each of these piezoelectric resonators were measured and the results are shown in Tables 1, 2, and 3. Table 1 indicates the measured results of the

piezoelectric resonator shown in FIG. **8**. Table 2 indicates the measured results of the piezoelectric resonator shown in FIG. **9**. Table 3 indicates the measured results of the piezoelectric resonator shown in FIG. **10**.

TABLE 1

	Basic longitudinal vibration	Longitudinal triple-wave vibration	Width-mode vibration
Resonant frequency (MHZ)	0.460	1.32	1.95
Electromechanical coupling coefficient (%)	18.9	3.9	25.2

TABLE 2

	Basic longitudinal vibration	Longitudinal triple-wave vibration	Width-mode vibration
Resonant frequency (MHZ)	0.455	1.44	1.96
Electromechanical coupling coefficient (%)	42.9	12.2	4.0

TABLE 3

	Basic longitudinal vibration	Square-type triple-wave vibration	Thickness-mode vibration
Resonant frequency (MHZ)	0.458	1.25	5.65
Electromechanical coupling coefficient (%)	35.0	11.5	23.3

It is understood from the measurement data that a stiffened piezoelectric resonator has a larger electromagnetic coupling coefficient K than an unstiffened piezoelectric resonator, and therefore has a larger frequency difference ΔF between the resonant frequency and the antiresonant frequency. The largest spurious vibration in a stiffened piezoelectric resonator is a longitudinal triple-wave type and the electromagnetic coupling coefficient K is 12.2% during vibration. During width-mode vibration, which is different from basic vibration, the electromagnetic coupling coefficient K is 4.0%. In contrast, the electromagnetic coupling coefficient K during width-mode vibration is 25.2% in an unstiffened longitudinal-vibration piezoelectric resonator. In an unstiffened square-type vibration piezoelectric resonator, the electromagnetic coupling coefficient K is as large as 23.3% during thickness-mode vibration. Therefore, it is understood that a stiffened piezoelectric resonator has smaller spurious vibrations than an unstiffened piezoelectric resonator.

In order to connect the electrodes **14** provided in the base member **12** to the external electrodes **20** and **22**, internal electrodes **14** may alternately extend to opposite side surfaces of the base member **12** as shown in FIG. **11**. On the opposite side surfaces of the base member **12**, external electrodes **20** and **22** are provided. In the piezoelectric resonator **10**, since the electrodes **14** are exposed alternately, the alternate electrodes **14** are connected to the external electrodes **20** and **22**, respectively, by disposing the external electrodes **20** and **22** on the side surfaces of the base member

12. Therefore, there is no need to provide insulating film on the side surfaces of the base member 12. An electrode 14 is preferably not formed so as to cover the entire area of a cross section of the base member 12 in this piezoelectric resonator 10. Therefore, an opposing area of adjacent electrodes 14 is smaller than that of adjacent electrodes 14 which are preferably formed to cover the entire cross section of the base member 12. By changing the opposing area of the electrodes 14, the capacitance and ΔF of the piezoelectric resonator 10 can be easily adjusted.

As shown in FIG. 12, an active section which is piezoelectrically active and an inactive section which is piezoelectrically inactive can be provided in the base member 12 of the piezoelectric resonator 10. In this case, for example, electrodes 14 are not provided at the opposite end surfaces of the base member 12, and some electrodes 14 disposed near opposite end surfaces of the base member 12 are preferably successively covered by the insulating films 16 and 18. In this preferred embodiment, three consecutive electrodes 14 located at each end of the base member 12 are preferably covered by the insulating film 16, and two consecutive electrodes 14 located at each end of the base member 12 are covered by the insulating film 18. External electrodes 20 and 22 are provided on the side surfaces of the base member 12 on which the insulating films 16 and 18 are disposed. The internal electrodes 14 are thereby connected to the external electrodes 20 and 22. Some of the electrodes 14 disposed at the opposite ends of the base member 12 are, however, not connected to the external electrodes 20 and 22.

At the approximate center of the base member 12, the base member 12 is preferably piezoelectrically active because an electric field is applied between adjacent electrodes 14. The base member 12 is preferably piezoelectrically inactive at opposite ends thereof because an electric field is not applied between adjacent electrodes 14 since the electrodes 14 are insulated. Therefore, an active section 24 for receiving input signals is defined at the approximate center portion of the base member 12 as shown by hatching in FIG. 12. Inactive sections 26 which do not respond to input signals are also preferably defined at the opposite ends of the base member 12.

In the piezoelectric resonator 10, the inactive section 26 is preferably provided at both ends of the base member 12. The inactive section 26 is adapted to be easily changed to adjust the resonant frequency and the difference ΔF between the resonant frequency and the antiresonant frequency. For example, by grinding the end surfaces in the longitudinal direction of the base member 12 or by adding mass to the inactive section, the resonant frequency and/or the antiresonant frequency of the piezoelectric resonator 10 can easily be adjusted.

In the piezoelectric resonator 10, as described before, the capacitance of the resonator can easily be adjusted by, for example, changing the number of piezoelectric layers in the base member 12. In the base member 12, the piezoelectric layers and electrodes 14 are preferably alternately stacked and electrically connected in parallel. When the number of layers is changed with the total length of the base member 12 remaining constant, the following relationship is satisfied since the thickness of one layer is inversely proportional to the number of layers:

Capacitance of resonator (the number of layers in active section/thickness of a layer) (the number of layers in active section)² wherein the symbol is defined as "is proportional to." Thus, the capacitance of the resonator is proportional to the

square of the number of layers in the active section of the base member 12. Therefore, the number of layers in the active section of the base member 12 is easily changed to adjust the capacitance of the piezoelectric resonator 10. This structural arrangement results in the piezoelectric resonator 10 having a high degree of freedom and flexibility in capacitance design. Therefore, it is easy to achieve impedance matching with an external circuit when the piezoelectric resonator 10 is mounted on a circuit board.

In another example, electrically conductive paste including, for example, silver, palladium, and an organic binder, was applied to one surface of each green sheet 30 made from piezoelectric ceramic. A plurality of such green sheets were stacked alternately and baked integrally at about 1200° C. to form a laminated block 34 measuring approximately 20 mm by 30 mm by 3.9 mm. External electrodes 38 and 40 were formed by sputtering. A high DC electric field was applied between adjacent internal electrodes 36 to polarize the laminated block such that the directions of polarization in adjacent piezoelectric layers were alternately opposed. The thickness of the laminated block 34 was changed. The laminated block 34 was cut to form a plate-shaped block 42 measuring approximately 1.5 mm by 30 mm by 3.8 mm. Every other electrode 36 exposed at the side surfaces of the plate-shaped block 42 were covered by a resin insulating material 44 and a silver electrode was disposed thereon by sputtering. The resultant block was cut by a dicing machine to obtain a piezoelectric resonator 10 measuring approximately 1.5 mm by 1.5 mm by 3.8 mm.

The piezoelectric resonator 10 had nineteen electrodes 14 in the base member 12, the electrodes 14 being disposed at an almost equal interval of about 0.19 mm. Insulating films 16 and 18 were formed so as to avoid applying an electric field to three piezoelectric layers disposed at both ends of the base member 12. An active section 24 included 14 piezoelectric layers disposed at the approximate center of the base member 12, and an inactive section 26 had three piezoelectric layers at both ends. The piezoelectric resonator 10 had a capacitance of 830 pF and the frequency characteristics shown in FIG. 13. For comparison, the frequency characteristics of a square-type vibration piezoelectric resonator is shown in FIG. 14. It is clearly seen from FIGS. 13 and 14 that the piezoelectric resonator 10 according to the preferred embodiments of the present invention has much less spurious vibration than the square-shaped piezoelectric resonator.

Depending on the positions where active sections 24 and inactive sections 26 are located, the frequency difference ΔF between the resonant frequency and the antiresonant frequency changes. Inactive sections 26 can be provided, for example as shown in FIG. 15, at both ends and the approximate center of the base member 12. The finite element method was used to calculate changes in capacitance C_f and frequency difference ΔF in the piezoelectric resonator for changing positions of the active sections, where "a" indicates the distance between the center and an end of the piezoelectric resonator 10, "b" indicates the distance between the center and the center of gravity of an active section 24, "c" indicates the length of the active sections 24, W indicates the width of the base member 12, and T indicates the thickness of the base member 12. FIG. 16 shows the relationship between b/a , and the ratio of ΔF to the antiresonant frequency F_a , $\Delta F/F_a$, and the capacitance C_f with "a" being equal to about 1.89 mm, W and T equal to about 0.8 mm, "c" equal to about 0.86 mm, and b/a changing. From FIG. 16, it is clearly seen that the capacitance C_f does not change according to the changing positions of the active sections 24. In contrast, it was also determined that ΔF

decreases as the active sections approach the two opposite ends of the base member **12**.

The frequency difference ΔF can be easily changed in the piezoelectric resonator **10** by changing the ratio of the active sections **24** to the inactive sections **26**. with a changing active-section ratio, which is a ratio of the length of the active section **24** to a total length of the base member **12** in the piezoelectric resonator **10** shown in FIG. **12**, the resonant frequency F_r , the antiresonant frequency F_a , the frequency difference ΔF , and its rate of change were measured and are indicated in Table 4 and FIG. **17**.

TABLE 4

Active-section length (mm)	Active-section ratio (%)	F_r (kHz)	F_a (kHz)	ΔF (kHz)	ΔF change rate (%)
1.80	100.0	1047.4	1163.4	115.9	0.0
1.70	94.4	1042.4	1163.4	120.9	4.3
1.60	88.9	1038.6	1163.4	124.8	7.6
1.53	85.0	1036.6	1163.4	126.8	9.4
1.50	83.3	1035.9	1163.4	127.5	9.9
1.40	77.8	1034.5	1163.4	128.9	11.2
1.35	75.0	1034.3	1163.4	129.1	11.4
1.30	72.2	1034.3	1163.4	129.0	11.3
1.20	66.7	1035.5	1163.4	127.9	10.3
1.17	65.0	1036.1	1163.4	127.2	9.7
1.10	61.1	1038.1	1163.4	125.3	8.1
1.00	55.6	1042.0	1163.4	121.4	4.7
0.90	50.0	1047.4	1163.4	115.9	0.0
0.80	44.4	1054.3	1163.4	109.1	-5.9
0.70	38.9	1062.7	1163.4	100.6	-13.2
0.60	33.3	1072.7	1163.4	90.7	-21.8
0.50	27.8	1084.2	1163.4	79.1	-31.7
0.40	22.2	1097.3	1163.4	66.1	-43.0
0.30	16.7	1111.9	1163.4	51.5	-55.6
0.20	11.1	1127.9	1163.4	35.5	-69.4
0.10	5.6	1145.2	1163.4	18.2	-84.3

FIG. **17** shows the relationship between the active-section ratio and change in ΔF under the condition in which ΔF is set to 100% when the active-section ratio is 100%, namely when an inactive section does not exist. It is clearly seen from FIG. **17** that ΔF is large at an active-section ratio of 65% to 85% with the peak ΔF being obtained at an active-section ratio of 75%. The peak value is larger by about 10% than the ΔF obtained when the active-section ratio is 100%, in other words, when an inactive section does not exist. The same ΔF is obtained at active-section ratios of 50% and 100%. Therefore, to obtain a piezoelectric resonator having a large ΔF , the active-section ratio should be set to be substantially equal to about 50% or more.

In the piezoelectric resonator **10**, when **14** piezoelectric layers constituted the active section **24** among 20 layers, the capacitance was 830 pF. In contrast, when the active-section ratio was set to 100%, which means that only one piezoelectric layer was used, in other words, when electrodes were disposed at two opposite end surfaces of the base member **12**, with the same material and the same dimensions, the capacitance was 3.0 pF. When all of the **24** piezoelectric layers constituted the active section **24**, the capacitance was 1185.6 pF. By changing the number of piezoelectric layers in the active section **24** of the base member **12** in the piezoelectric resonator **10**, the capacitance can easily be changed within a range of about 400-times difference between the minimum and maximum. Therefore, by changing the lamination structure of the piezoelectric resonator **10**, the capacitance can be selected from a wide range which provides a large degree of flexibility and freedom in capacitance design.

In order to connect the electrodes **14** disposed inside the base member **12** to the external electrodes **20** and **22**, insulating films **16** and **18** having windows **50** may be provided such that every other electrode **14** is exposed as shown in FIG. **18**. The external electrodes **20** and **22** are preferably provided on the insulating films **16** and **18**, and the electrodes **14** alternately connect to the two external electrodes **20** and **22**. Two external electrodes **20** and **22** may be disposed on one side surface of the base member **12** as shown in FIG. **19**. Insulating films **16** and **18** are preferably disposed on one side surface of the base member **12** in a two-row arrangement and two rows of connection sections are preferably provided. These two rows of insulating films **16** and **18** are disposed respectively on every other electrode **14**. On these two rows of insulating film **16** and **18**, two rows of external electrodes **20** and **22** are preferably disposed, respectively. The piezoelectric resonators having these modifications achieve the same advantages as the above-described piezoelectric resonator. Also in the piezoelectric resonator **10** in which internal electrodes **14** are alternately exposed at side surfaces of the base member **12** as shown in FIG. **20**, an active section **24** and inactive sections **26** can be provided.

The capacitance and ΔF of the piezoelectric resonator **10** in which internal electrodes **14** are alternately exposed as shown in FIG. **20** can be changed by adjusting the opposing areas of adjacent electrodes **14**. Using the finite element method, with the gap G between the end of an electrode **14** and the side surface of the base member **12** in the thickness direction being changed, the antiresonant frequency F_a , capacitance C_f , and ΔF of a piezoelectric resonator having a base member **12** which is approximately 3.74 mm long, 0.8 mm wide, 1.0 mm thick, and having an active section **24** which is approximately 3.6 mm long, inactive sections **26** disposed at both ends which are approximately 0.07 mm long and **20** piezoelectric layers each being approximately 0.18 mm thick, as shown in FIG. **21**, were calculated. The results are shown in Table 5 and FIG. **22**. It is found from Table 5 and FIG. **22** that C_f and ΔF become smaller as the gap G increases, in other words, as the opposite area of the electrodes **14** becomes smaller.

TABLE 5

Gap G (μm)	F_a (kHz)	F_a change rate (%)	C_f (pF)	C_f change rate (%)	ΔF (kHz)	ΔF change rate (%)
1	546.37	-0.52	267.58	27.47	53.36	30.15
50	546.75	-0.45	264.40	25.96	52.71	28.56
100	547.38	-0.33	251.69	19.90	50.05	22.07
150	548.20	-0.18	232.38	10.70	45.89	11.93
200	549.20	0.00	209.91	0.00	41.00	0.00
250	550.61	0.26	181.96	-13.32	35.06	-14.49
300	552.11	0.53	156.44	-25.47	29.75	-27.44

Electrodes **14** may be formed such that they extend to different end surfaces on the same side of piezoelectric layers as shown in FIG. **23** in a piezoelectric resonator **10** which is a modified example of the above-described piezoelectric resonator **10**. By laminating these two types of piezoelectric layers, two rows of electrodes **14** are preferably exposed on one side surface of the base member **12** as shown in FIG. **24**. Therefore, by forming external electrodes **20** and **22** at portions where the electrodes **14** are exposed, the electrodes **14** are alternately connected to the external electrodes **20** and **22**.

In the piezoelectric resonator **10** in which each electrode **14** is formed to cover an entire cross section of the base

member **12** as shown FIGS. **2** and **12**, since an electric field is applied to the entire cross section of the base member **12**, the electromagnetic coupling coefficient of the resonator is large and thus ΔF is large. The capacitance of the piezoelectric resonator **10** is therefore also large. When the laminated block is cut to produce a plurality of the piezoelectric resonators **10**, since each electrode has been formed to cover almost the entire cross section of the laminated block in advance, each piezoelectric resonator has an electrode which covers the entire cross section even if the cut position shifts. Therefore, it is not necessary to precisely determine the positions at which the laminated block is cut. By changing the direction of cutting, resonators having different cross sections, different areas, and different capacitances are obtained from the same piezoelectric, ceramic, laminated block. Resonators having various capacitances and various ΔF can be obtained according to which electrode end section has insulating film. As described above, many types of piezoelectric resonators can be obtained from the same laminated block.

In contrast, to produce a piezoelectric resonator having a gap between an end of each electrode **14** and the side surface of the base member **12** as shown in FIGS. **11** and **20**, it is necessary to cut a laminated block after positioning such that the gap is correctly formed. In such a piezoelectric resonator, however, it is not necessary to provide insulating film on a side surface of a base member, and the number of manufacturing steps is substantially reduced.

An inactive section **26** may be formed such that an electric field is not applied by not providing electrodes **14** on an end of the base member **12** as shown in FIG. **25**. The end of the base member **12** may be polarized or may not be polarized. As shown in FIG. **26**, it is possible for only the end of the base member **12** to be not polarized. In this case, even if an electric field is applied between the electrodes **14**, a portion which is not polarized is piezoelectrically inactive. In other words, only when a piezoelectric layer is polarized and an electric field is applied, does the layer become piezoelectrically active, otherwise the layer is inactive. In this configuration, the capacitor is disposed in the inactive section, and the capacitance is increased. A small electrode **52** may be provided on an end surface of the base member **12** as shown in FIG. **27** in order to adjust the frequency or to connect to an external circuit.

Using such a piezoelectric resonator **10**, electronic components such as oscillators and discriminators are produced. FIG. **28** is a perspective view of an electronic component **60**. The electronic component **60** includes an insulating substrate **62**. At opposing end portions of the insulating substrate **62**, two indentations **64** are preferably formed, respectively. On one surface of the insulating substrate **62**, two pattern electrodes **66** and **68** are formed as shown in FIG. **29**. One pattern electrode **66** is disposed between opposing indentations and extends in a substantially L-shaped manner from a point near one end toward the center of the insulating substrate **62**. The other pattern electrode **68** is disposed between opposing indentations **64** and extends substantially straight from a point near the other end toward the center of the insulating substrate **62**. The pattern electrodes **66** and **68** are arranged such that they are routed in a roundabout fashion from the ends of the insulating substrate **62** to the opposite surface.

At one end of the pattern electrode **66** disposed at the center of the insulating substrate **62**, a protrusion **70** is formed with electrically conductive adhesive. As shown in FIG. **30**, the above-described piezoelectric resonator **10** is preferably mounted on the protrusion **70** such that the

approximate center of the base member **12** at a location of a node point of the base member is disposed on the protrusion **70**. An external electrode **22** of the piezoelectric resonator **10** is, for example, connected to the protrusion **70**. The other external electrode **20** is connected to a pattern electrode **68** preferably with electrically conductive wire **72**. The electrically conductive wire **72** is preferably connected to the approximate center of the external electrode **20** of the piezoelectric resonator **10**. The protrusion **70** may be provided on the piezoelectric resonator **10**. In this case, the protrusion **70** provided for the piezoelectric resonator **10** is mounted on the pattern electrode **66** with electrically conductive adhesive.

A metal cap **74** is preferably placed on the insulating substrate **62** to complete the electronic component **60**. To prevent the metal cap **74** from being short-circuited to the pattern electrodes **66** and **68**, insulating resin is preferably applied to the insulating substrate **62** and the pattern electrodes **66** and **68** in advance. The electronic component **60** uses the pattern electrodes **66** and **68**, which are arranged such that they are routed to the rear surface from ends of the insulating substrate **62**, as input and output terminals for connecting to external circuits.

Since the approximate center of the piezoelectric resonator **10** is connected to the protrusion **70** in this electronic component **60**, the ends of the piezoelectric resonator **10** are disposed separately from the insulating substrate **62** so vibration is not prevented or damped. Excited longitudinal vibration is not weakened because the approximate center of the piezoelectric resonator, which serves as a node, is secured to the protrusion **70** and is connected to the electrically conductive wire **72**.

The electronic component **60** is preferably mounted on a circuit board together with IC chips and other components to form an oscillator and a discriminator. Since the electronic component **60** is sealed and protected by the metal cap **74**, it can be used as a chip-type, surface-mountable component which can be mounted by reflow soldering or other suitable methods.

When the electronic component **60** is used in an oscillator, spurious vibrations are suppressed to a low level and unusual vibration caused by the spurious vibrations are prevented due to the unique structure and arrangement of the piezoelectric resonator **10** used in the electronic component **60**. It is also easy to achieve impedance matching with an external circuit since the capacitance of the piezoelectric resonator **10** can be set to any desired value. Especially when the electronic component is used for an oscillator for voltage-controlled oscillation, a wide frequency range which cannot be obtained conventionally is achieved as a result of a large ΔF of the resonator.

When the electronic component **60** is used for a discriminator, a wide peak-separation range is achieved as a result of a large ΔF of the resonator. In addition, since the resonator provides a wide capacitance range, it is easy to achieve impedance matching with an external circuit.

The piezoelectric resonator **10** may be preferably mounted on the insulating substrate **62** so that two protrusions **70** made from an electrically conductive material such as electrically conductive adhesive are provided on both pattern electrodes **66** and **68**, and the external electrodes **20** and **22** of the piezoelectric resonator **10** are connected to the two protrusions **70**, as shown in FIGS. **31** and **32**. The piezoelectric resonator **10** may also be mounted on the insulating substrate **62** in a way shown in FIGS. **33** and **34** in which two protrusions **70** made from an insulating material such as insulating adhesive are formed on the

insulating substrate **62** and the external electrodes **20** and **22** are connected to the pattern electrodes **66** and **68** with electrically conductive wire **72**.

A ladder filter can be constructed to contain at least one, but preferably, a plurality of the piezoelectric resonators **10**. As shown in FIGS. **35** and **36**, three pattern electrodes **76**, **78**, and **80** are disposed on an insulating substrate **62** in this electronic component **60**. Protrusions **82** and **86** are formed with electrically conductive adhesive on both-end pattern electrodes **76** and **80**. On the center pattern electrode **78**, two protrusions **84** and **88** are formed with electrically conductive adhesive.

One external electrode **22** for each of piezoelectric resonators **10a**, **10b**, **10c**, and **10d** is mounted on each of the protrusions **82**, **84**, **86**, and **88**, respectively. The other external electrodes **20** for piezoelectric resonators **10a**, **10b**, and **10c** are connected to each other with electrically conductive wire **72**. The other external electrode **20** of a piezoelectric resonator **10d** is connected to the pattern electrode **80** with electrically conductive wire **72**. A metal cap **74** is placed on the insulating substrate **62**.

The electronic component **60** is used as a ladder filter having a ladder-shaped circuit shown in FIG. **37**. Two piezoelectric resonators **10a** and **10c** serve as series resonators and the other two piezoelectric resonators **10b** and **10d** serve as parallel resonators. In such a ladder filter, the parallel piezoelectric resonators **10b** and **10d** are designed to have substantially larger capacitances than the series piezoelectric resonators **10a** and **10c**.

Attenuation in the ladder filter is determined by the capacitance ratio between the series resonators and the parallel resonators. In this electronic component **60**, the capacitance can be adjusted by changing the number of laminated layers used in the piezoelectric resonators **10a** to **10d**. Therefore, a ladder filter having a larger attenuation with fewer resonators is implemented by changing the capacitances of the piezoelectric resonators, as compared with a case where the conventional unstiffened piezoelectric resonators are used. Since the piezoelectric resonators **10a** to **10d** have a larger ΔF than the conventional piezoelectric resonator, a wider transmission frequency band is achieved as compared with the conventional piezoelectric resonator.

A two-terminal electronic component **60** such as a resonator and a discriminator can be produced with a piezoelectric resonator **10** as shown in FIG. **38**. Two terminals **90** made from an electrically conductive material are prepared to produce such a two-terminal component **60**. These terminals **90** are formed such that they extend from hoops **92**. Practically, a plurality of terminals **90** are formed on each hoop **92** and arranged in line. A terminal **90** is provided with a fold section **94** at the intermediate portion and an H-shaped support member **96** at the end. The support member **96** is bent and is provided with a protruded mounting member **98** at the center. The two terminals **90** are disposed such that their mounting members **98** oppose each other.

The piezoelectric resonator **10** is supported between the mounting members **98**. The mounting members **98** abut against the external electrodes **20** and **22** preferably at the center of the piezoelectric resonator in the longitudinal direction. Since the terminals **90** have fold sections **94**, which serve as spring elements, the piezoelectric resonator **10** is spring-supported by the terminals **90**. A case **100** having an opening at one end is placed on the piezoelectric resonator **10**. The opening of the case **100** is preferably closed with paper and then resin-sealed. The terminals **90** are cut from the hoops **92** to complete the electronic component **60**. The electronic component **60** having a shape other than a chip-shape can thus be made.

Since the base member **12** has a laminated structure, the capacitance of the piezoelectric resonator **10** according to the preferred embodiments of the present invention can be set to any desired value and it is easy to achieve impedance matching with an external circuit. Since the preferred embodiments of the present invention provide a stiffened piezoelectric resonator, the resonator has a larger ΔF and a wider frequency band than the conventional unstiffened piezoelectric resonator. In addition, the stiffened piezoelectric resonator has small spurious vibrations. Furthermore, by adjusting the sizes and positions of the active section and the inactive sections, ΔF can easily be changed. Since the electronic component **60** according to the preferred embodiments of the present invention has a simple structure, it can be produced at a low cost while achieving the above-described features and advantages of the piezoelectric resonator **10**.

Since the piezoelectric resonator **10** according to the preferred embodiments of the present invention includes more parameters which can be designed than the conventional piezoelectric resonator, various desirable resonator characteristics are achieved. The relationships between these parameters, $\Delta F/F_a$ and capacitance C_f are indicated in FIG. **39**. It is understood from FIG. **39** that these parameters increase the degree of flexibility and freedom in designing the characteristics of the piezoelectric resonator **10**.

While the invention has been particularly shown and described with reference to preferred embodiments thereof, it will be understood by those skilled in the art that the foregoing and other changes in form and details may be made therein without departing from the spirit and scope of the invention.

What is claimed is:

1. A piezoelectric resonator comprising:

a piezoelectric base member including a plurality of piezoelectric layers and a plurality of electrodes; means for driving said piezoelectric base member; and a support substrate supporting said piezoelectric base member; wherein

at least two of said piezoelectric layers are stacked on each other and at least one of said plurality of electrodes is disposed between said at least two of said piezoelectric layers and said at least two of said piezoelectric layers are polarized in opposite directions such that a longitudinal basic vibration is generated in said base member along a longitudinal axis of the piezoelectric base member and said piezoelectric base member is displaced along the longitudinal axis when said means for driving said piezoelectric base member applies an electric field to said at least one of said plurality of electrodes and such that a single vibration node at which point substantially no vibration occurs is defined at an approximate center of the piezoelectric base member and said piezoelectric base member is supported on said support substrate only at a location of said single vibration node located at the approximate center of the piezoelectric base member.

2. A piezoelectric resonator according to claim 1, wherein said plurality of piezoelectric layers and said plurality of electrodes are arranged in a laminated stack which defines an integral unit.

3. A piezoelectric resonator according to claim 1, wherein each of said plurality of piezoelectric layers is arranged to vibrate in a thickness vibrating mode and said plurality of piezoelectric layers and said plurality of electrodes are arranged in a laminated stack such that said base member vibrates in a longitudinal vibration mode as an integral unit.

4. A piezoelectric resonator according to claim 1, wherein said plurality of piezoelectric layers and said plurality of electrodes are stacked and define an integral unit, each of said plurality of electrodes is disposed between adjacent ones of said piezoelectric layers, each of said piezoelectric layers located between adjacent ones of the electrodes is polarized in a direction that is opposite to a direction of polarization of at least one adjacent piezoelectric layer.

5. A piezoelectric resonator according to claim 1, wherein said base member is polarized in opposite directions at both sides of at least one of said plurality of electrodes.

6. A piezoelectric resonator according to claim 1, wherein said base member includes an active section constituting a first portion of said base member and at least one inactive section constituting a second portion of said piezoelectric base member.

7. A piezoelectric resonator according to claim 6, wherein said active section is polarized in a longitudinal direction of said base member and arranged to generate a longitudinal vibration in said base member when an electric field is applied in the longitudinal direction of said base member, said at least one inactive section is not polarized or not energized by an electric field.

8. A piezoelectric resonator according to claim 6, wherein said at least one inactive section is disposed at one of two opposite ends of said active section and extends to an end at said base member.

9. A piezoelectric resonator according to claim 6, wherein said active section occupies at least approximately 50% of the length of said base member which extends in the longitudinal direction of said base member.

10. A piezoelectric resonator according to claim 1, wherein said plurality of electrodes are arranged substantially perpendicular to a longitudinal direction of said base member.

11. A piezoelectric resonator according to claim 1, wherein said at least one pair of electrodes comprise internal electrodes, the piezoelectric resonator further comprising a pair of external electrodes each disposed on one of two opposite side surfaces of the base member and extending along a length of the base member.

12. A piezoelectric resonator according to claim 1, wherein said plurality of electrodes each includes an exposed portion which extends to an external surface of the base member, wherein the plurality of electrodes are alternately covered by insulating film disposed on opposite side surfaces of the base member such that each insulating film covers an exposed portion of every other one of the plurality of electrodes.

13. A piezoelectric resonator comprising:

a piezoelectric base member including a plurality of piezoelectric layers and a plurality of electrodes; means for driving said piezoelectric base member; and a support substrate supporting said piezoelectric base member; wherein

said plurality of piezoelectric layers and said plurality of electrodes are arranged in a laminated stack which defines an integral unit and which is arranged such that when said means for vibrating said piezoelectric base member applies an electric field to the piezoelectric base member, the piezoelectric base member vibrates in a longitudinal vibration mode along a longitudinal axis of the piezoelectric base member and said piezoelectric base member is displaced along the longitudinal axis such that a single vibration node at which point substantially no vibration occurs is defined at an approximate center of the piezoelectric base member and said

piezoelectric base member is supported on said support substrate only at a location of said single vibration node located at the approximate center of the piezoelectric base member.

14. A piezoelectric resonator comprising:

a piezoelectric base member including a plurality of piezoelectric layers and a plurality of electrodes; means for driving said piezoelectric base member; and a support substrate supporting said piezoelectric base member; wherein

each of said plurality of piezoelectric layers is arranged to vibrate in a thickness mode and said plurality of piezoelectric layers and said plurality of electrodes are arranged in an integral stack such that when said means for vibrating said piezoelectric base member applies an electric field to the piezoelectric base member, said base member vibrates in a longitudinal vibration mode along a longitudinal axis of the piezoelectric base member and said piezoelectric base member is displaced along the longitudinal axis such that a single vibration node at which point substantially no vibration occurs is defined at an approximate center of the piezoelectric base member and said piezoelectric base member is supported on said support substrate only at a location of said single vibration node located at the approximate center of the piezoelectric base member.

15. An electronic component comprising:

a substrate;

a mounting member mounted on said substrate;

at least one piezoelectric resonator including a piezoelectric base member including a plurality of piezoelectric layers and a plurality of electrodes;

means for driving said at least one piezoelectric resonator; wherein

at least two of said piezoelectric layers being stacked on each other and at least one of said plurality of electrodes being disposed between said at least two of said piezoelectric layers and said at least two of said piezoelectric layers are polarized in opposite directions, and being arranged such that when said means for vibrating said piezoelectric base member applies an electric field to the piezoelectric base member, the piezoelectric base member vibrates in a longitudinal vibration mode along a longitudinal axis of the piezoelectric base member and said piezoelectric base member is displaced along the longitudinal axis such that a single vibration node at which point substantially no vibration occurs is defined at an approximate center of the piezoelectric base member and such that a vibration node at which point substantially no vibration occurs is defined at an approximate center of the piezoelectric base member, said at least one piezoelectric resonator being mounted on said substrate via said mounting member such that the piezoelectric base member is supported only at said single node point at the approximate center of the piezoelectric base member;

a cap disposed on said substrate for covering said base member.

16. An electronic component comprising:

a substrate having a pattern electrode disposed thereon; a mounting member mounted on said pattern electrode on said substrate;

a plurality of piezoelectric resonators including a piezoelectric base member containing a plurality of piezoelectric layers and a plurality of internal electrodes;

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means for vibrating said plurality of piezoelectric resonators; wherein
 at least two of said piezoelectric layers being stacked on each other and at least one of said plurality of electrodes is disposed between said at least two of said piezoelectric layers and said at least two of said piezoelectric layers are polarized in opposite directions and are arranged such that when said means for vibrating said piezoelectric base member applies an electric field to the piezoelectric base member, the piezoelectric base member vibrates in a longitudinal vibration mode along a longitudinal axis of the piezoelectric base member and said piezoelectric base member is displaced along the longitudinal axis such that a single vibration node at which point substantially no vibration occurs is defined at an approximate center of the piezoelectric

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base member, said piezoelectric base member including at least one pair of external electrodes being arranged such that each of said plurality of internal electrodes is electrically connected to one of said at least one pair of external electrodes, said at least one piezoelectric resonator being mounted on said pattern electrode on said substrate via said mounting member such that said pattern electrode is electrically connected to said at least one pair of external electrodes such that the piezoelectric base member is supported only at said single node point at the approximate center of the piezoelectric base member; and
 a cap disposed on said substrate for covering said base member.

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